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Discounting of Probabilistic Reinforcers by Pigeons

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by

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Este trabalho é dedicado aos meus pais.

ABSTRACT OF THE DISSERTATION

Discounting of Probabilistic Reinforcers by Pigeons

by

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Professor Leonard Green, Chair

The phenomenon of probability discounting – the decrease in the subjective value of an outcome as the likelihood of its receipt decreases – has been an increasingly explored area of research with human participants, but has received little attention with nonhuman animals. The few studies that have attempted to obtain probability discounting functions with animals have serious limitations. For example, in Wilhelm and Mitchell's (2008) study with rats, the experienced probabilities often differed markedly from the programmed probabilities. Green, Myerson, and Calvert's study with pigeons (2010) used repeated gambles rather than one-shot choices, which is the typical situation studied with humans, and the time to reinforcement, rather than the probability of reinforcement, may well have determined the animals' behavior.

The current work developed an innovative procedure, one that combined the concurrent-chains and the adjusting-amount procedures, to study probability discounting in pigeons. The concurrent-chains procedure included a non-independent VI 30-second schedule in the initial link, during which pigeons revealed their preference between a smaller, more likely reinforcer and a larger, but less likely reinforcer. The adjusting-amount procedure allowed for the estimation of the subjective value of the probabilistic reinforcer.

In Experiment 1, pigeons were presented choices between a smaller, certain amount and a larger, probabilistic amount at each of five probabilities (10%, 25%, 50%, 75%, and 90%). In Experiment 2, the probabilities associated with each reinforcer were multiplied by three different values (1.0, 0.75, and 0.25) in order to determine subjective values when both reinforcers were probabilistic while the ratio of the probabilities between the smaller and larger reinforcers was held constant. Finally, in Experiment 3 the same concurrent-chains procedure was used but with delay to rather than probability of reinforcement manipulated. Specifically, the pigeons chose between a smaller, immediate reinforcer and a larger, delayed reinforcer. The purpose of Experiment 3 was to determine whether the new procedure, which combines a concurrent-chains procedure with an adjusting-amount procedure, would produce results similar to those with standard adjusting-amount procedures. An amount manipulation (in which the larger reinforcer was 16 food pellets and 32 food pellets in different phases) was included in all three experiments to test for an amount effect in discounting.

The discounting of the larger reinforcer increased as the odds against (Experiments 1 and 2) or delay to (Experiment 3) its receipt increased. Data were well described by the hyperbolic discounting model. Consistent with most animal discounting studies, no amount effect was observed (i.e., degree of discounting did not vary as a function of the amount of the larger reinforcer).

To our knowledge, this study is the first to demonstrate probability discounting in nonhuman animals that ensures that the probabilities the animals actually experienced matched those programmed. Furthermore, the procedure provides an alternative technique that may allow one to directly compare delay and probability discounting mechanisms in animals.

Introduction

Humans and nonhuman animals are constantly making choices: Where to forage, what food to eat, what route to take to get home, etc. In some situations, choices are relatively easy to make, and it is relatively easy to predict what will be chosen. For example, when the choice is between two otherwise identical rewards that differ only in amount, there is a tendency to choose the larger over the smaller; when choosing between rewards of the same amount that differ only in when they can be received, the tendency is to choose the one that can be received sooner over the one that would be received later; and when choosing between rewards of the same amount that differ only in their likelihood of receipt, the tendency is to choose the more certain over the less certain. Choices are not as easy to predict, however, when the alternatives vary along more than one dimension, as is the case when the alternatives are a smaller reward that could be received immediately and a larger reward that could be received later or when the alternatives are a smaller reward that will be received with certainty and a larger reward that is probabilistic. This is because the subjective value of a reward decreases as the delay to the reward's receipt increases, a phenomenon known as delay discounting, and as the probability to the reward's receipt decreases, a phenomenon known as probability discounting.

Delay discounting describes the fact that although a smaller, immediate reward might be chosen over a larger, delayed reward, if the delay to the larger reward were decreased, the immediate amount decreased, or the delayed amount increased, then the opposite choice might be observed, and the larger, delayed reward might be the one that is chosen. Probability discounting describes the fact that although a smaller, certain reward might be chosen over a larger, probabilistic reward, if the probability of the larger reward were increased, the certain amount decreased, or the probabilistic amount increased, then the opposite choice might be

observed, and the larger, probabilistic reward might be the one that is chosen. Psychologists and economists have described and modeled the processes of delay and probability discounting by studying choice situations that systematically varied the amount and type of rewards, as well as the delays and probabilities associated with those rewards (for reviews, see Frederick, Loewenstein, & O'Donoghue, 2002; Green & Myerson, 2004; Green, Myerson, & Vanderveldt, 2014).

Adjusting-Amount and Adjusting-Delay Procedures

In most delay and probability discounting studies, participants are presented with choices between different hypothetical amounts of money. The smaller amount is associated with a shorter delay or a higher probability, and the larger amount is associated with a longer delay or a lower probability. Following the participant's choice, one of the variables (amount or delay/probability) is adjusted accordingly, and a new choice is presented. The process is repeated until the participant is indifferent between the two amounts. This point of indifference is an estimate of the subjective value of the larger reward.

One common procedure used to obtain these subjective value estimates is the adjusting-amount procedure (Du, Green, & Myerson, 2002; Rachlin, Raineri, & Cross, 1991). In this procedure, an initial choice might be between receiving $100 immediately or $200 in six months. If the individual were to choose the $100 immediately, then the amount of this immediate reward would be decreased to, say, $50 on the next choice. If then the individual were to choose to wait six months for the $200, the amount of the immediate reward would be increased to $75. After a number of choices, this procedure converges on a point of subjective equality, that is, a point at which the participant is indifferent between the smaller, immediate reward and the larger, delayed reward. In order to obtain a fuller picture of how an individual discounts the delayed

$200 amount, the procedure is repeated with various delays to the larger reward. The several indifference points thus obtained can then be plotted as a discounting function describing how the subjective value of the $200 reward changes as the delay to its receipt increases (see Figure 1, left panel). Note that if a participant were more often to choose to wait for the larger reward, then the discounting function would be less steep than that of a participant who consistently chose to receive the smaller, immediate reward. In other words, the more impulsive (i.e., unwilling to wait) an individual is, the steeper the discounting function will be.

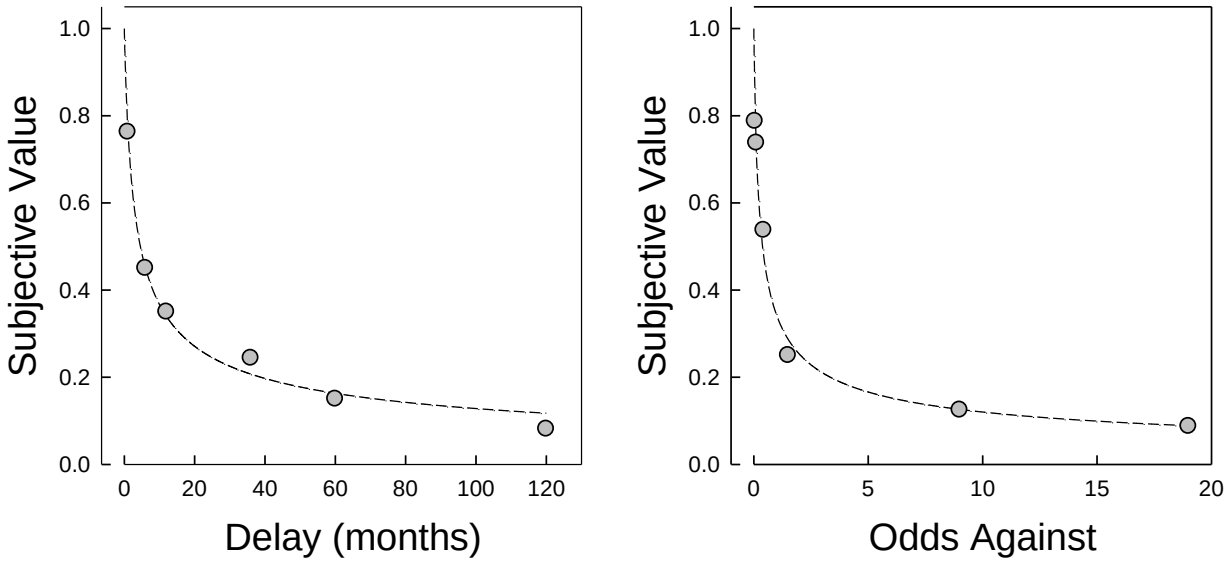

Figure 1. Examples of delay and probability discounting. In the left graph, the relative present subjective value of a delayed reward decreases as the delay to its receipt increases; in the right graph, the relative certain subjective value of a probabilistic reward decreases as the odds against its receipt increases. The curved lines represent the best-fitting hyperboloid discounting functions (Equation 1). Data are from Experiment 2 of "Amount of reward has opposite effects on the discounting of delayed and probabilistic outcomes," by L. Green, J. Myerson, and P. Ostaszewski, 1999, *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, p. 423.

The adjusting-delay procedure (Mazur, 1987) is a similar way of obtaining the subjective value of delayed rewards. In this case (using the same initial amounts and delays as above) one would present a participant with a choice between $100 to be received immediately and $200 to

be received after six months. If the participant were to choose the immediate reward, then the delay to the larger reward would be decreased for the next choice. If the participant were to choose the delayed reward, then the delay would be increased for the next choice. After a number of choices, an estimate of how long a delay is required for that participant to be indifferent between the immediate $100 and the delayed $200 is obtained (for reviews on different methods used to obtain discounting functions, see Holt, Green, & Myerson, 2012; Madden & Johnson, 2010).

The extension of the adjusting-amount procedure to probability discounting studies is rather straightforward. To use a similar example, suppose a participant were presented with an initial choice between $100 to be received for certain and $200 to be received with a 60% chance. If the participant were to choose the larger reward, then the amount of the certain reward would be increased, and the next trial would consist of a choice between a certain $150 reward and a $200 reward with a 60% chance. If the participant were then to choose the certain reward, its amount would be decreased, and the next trial would consist of a choice between a certain $125 reward and a $200 reward with a 60% chance. After a number of trials, an estimate of the certain subjective value of the $200 reward is obtained. This procedure would then be repeated across different probabilities associated with the $200 reward. The resulting discounting function would show how the subjective value of a probabilistic reward changes as the odds against its receipt increases (see Figure 1, right panel; to allow for a direct comparison between delay and probability discounting functions, probability of reward, p, is converted into odds against, Θ, such that $\Theta = [1-p] / p$). Note that, similarly to what occurs with delay discounting, the more a participant chooses the larger reward, the less steep the discounting

function. In other words, people who are more risk-seeking or more prone to taking chances will tend to show shallower discounting.

Discounting Model

Economists and psychologists have long sought to derive mathematical models to describe how people discount delayed or risky rewards. The hyperboloid model (Myerson & Green, 1995) has been shown to provide an excellent description of discounting:

$$V = A/(1 + bX)^{s}, \qquad \text{(Equation 1)}$$

where V is the present/certain value of a delayed/probabilistic reward of amount A. The parameter X represents either delay to the reward or odds against its receipt, b reflects the rate of discounting, and s is a non-linear scaling or weighting parameter (for details, see Green, Fry, & Myerson, 1994; Myerson, Green, & Morris, 2011).

Both delay and probability discounting have been widely studied in human subjects. Research has explored the effects of variables such as the amount of reward (e.g., Estle, Green, Myerson, & Holt, 2006; Kirby, 1997; Kirby & Maraković, 1996; Raineri & Rachlin, 1993), culture (Du et al., 2002), income (Green, Myerson, Lichtman, Rosen, & Fry, 1996), age (e.g., Green, Fry, & Myerson, 1994), and type of reward, such as edibles (e.g., Estle, Green, Myerson, & Holt, 2007; Odum, Baumann, & Rimington, 2006; Odum & Rainaud, 2003) and medical treatments (Chapman, 1996). Discounting has also been studied in different subpopulations, including individuals with heroin, cocaine, nicotine, alcohol and gambling addictions (e.g., Bickel, Odum, & Madden, 1999; Coffey, Gudleski, Saladin, & Brady, 2003; Madden, Petry, Badger, & Bickel, 1997; Petry & Casarella, 1999; Vuchinich & Simpson, 1998). Results from these studies revealed reliable patterns, thus showing that discounting is a robust phenomenon

and that the hyperboloid function provides an adequate description of the change in subjective value.

With regard to nonhuman animal subjects, several studies have investigated delay discounting using an adjusting-amount procedure similar to that used with humans. The typical differences between the procedure used with humans and animals are that, with the latter, rewards always have been primary reinforcers, and delays are much shorter (seconds rather than weeks, months, or years). Also, animals receive extensive experience with the choices, spending many sessions on the same delays or amounts, whereas in human studies all the conditions are usually presented in a single session.

For example, Richards, Mitchell, de Wit, and Seiden (1997, Experiment 1) studied how rats discounted a 100 µL water reinforcer across different delays (0, 2, 4, 8, and 16 s). Within each experimental session, the amount of the immediate water reinforcer was systematically adjusted based on the rats' choices. If the rat chose the smaller reinforcer amount, the amount of the immediate reinforcer was reduced by 10% on the next trial; if the rat chose the larger reinforcer amount, the amount of the immediate reinforcer was increased by 10% on the next trial (at the beginning of the session, the amount of water associated with the immediate option was either 35 µL or 71 µL for different rats). Whenever the rat chose either alternative twice in a row, the following trial would be a forced trial of the other type in order to ensure that the rats were frequently exposed to the consequences of each type of choice. The five delays to the larger amount were studied in different sessions over the course of a week, and they were introduced in different orders over the five weeks. Results showed that the rats reached stable performance (i.e., the indifference point between the two amounts) within the first 30 trials of the 60-trial daily session, thus showing that the adjusting-amount procedure was an adequate

technique for studying delay discounting in rats. Furthermore, results showed that, consistent with what is observed with humans, the preference for the larger reinforcer decreased systematically as the delay to its receipt increased.

The results of several other delay discounting studies using different species as well as different types of food, liquid, and drug reinforcers (e.g., Calvert, Green, & Myerson, 2010; Freeman, Green, Myerson, & Woolverton, 2009), have been consistent with the results obtained with human subjects, and also well fitted by the hyperboloid function (Equation 1; for a review, see, e.g., Green & Myerson, 2004). These results not only extend the generality of the discounting paradigm, but also support the view that discounting is a basic choice and decision-making process, common across a broad phylogenetic range, that possibly was selected for because of its survival value (Kagel, Green, & Caraco, 1986).

Even though the hyperboloid function describes both human and animal data well, several differences between human and animal discounting of delayed rewards have been reported. For example, with humans, an *s* parameter less than 1.0 often provides a significantly better fit to the data (Myerson & Green, 1995), whereas with animals the *s* parameter is seldom significantly different from 1.0 (e.g., Green, Myerson, Holt, Slevin, & Estle, 2004; Oliveira, Calvert, Green, & Myerson, 2013). In this case, with the *s* parameter equal to 1.0, Equation 1 reduces to a simple hyperbola (Mazur, 1987).

How do other aspects of delay discounting compare between humans and animals? Two of the most important and more widely studied phenomena are called the amount effect (also termed the magnitude effect) and preference reversals.

Amount Effect

A finding in the delay discounting literature that suggests a difference between humans and animals is referred to as the amount effect. Numerous studies have shown that humans discount larger delayed rewards less steeply than smaller delayed rewards, not only when the rewards are hypothetical monetary rewards (e.g., Benzion, Rapoport & Yagil, 1989; Green, Myerson, Oliveira, & Chang, 2013; Kirby, 1997; Thaler, 1981), but when other types of reward outcomes are studied, including consumable rewards like beer, soda, and candy (Estle et al., 2007; Odum et al., 2006), medical treatments (Chapman, 1996), heroin (Giordano et al., 2002), cigarettes (Baker, Johnson, & Bickel, 2003), job choices (Shoenfelder & Hantula, 2003), and vacation time (Raineri & Rachlin, 1993). It also has been observed in studies where real rewards were used, both monetary (Johnson & Bickel, 2002; Kirby, 1997) and consumable liquids (Jimura, Myerson, Hilgard, Braver, & Green, 2009). For example, Green, Myerson, and McFadden (1997) presented subjects with choices between a larger amount ($100, $2,000, $25,000, and $100,000 in different conditions) to be received after a delay (3 months, 6 months, 1 year, 3 years, 5 years, 10 years, and 20 years) and a smaller amount to be received immediately. Results showed that the rate of discounting decreased as the amount of the delayed reward increased up to the $25,000 amount, after which it leveled off.

The amount effect also has been observed in probability discounting studies with humans. For example, Green, Myerson, and Ostaszewski (1999) compared the effect of reward amount on the degree of discounting of delayed and of probabilistic rewards. Results for the delay discounting conditions were consistent with those reported by Green et al. (1997). In the probability discounting conditions, however, the authors reported an effect of amount in the direction opposite that of delay discounting – that is, larger probabilistic rewards were

discounted more steeply than smaller probabilistic rewards (see Figure 2 for a comparison). A number of other studies have obtained similar results (e.g., Christensen, Parker, Silberberg, & Hursh, 1998; Kirby & Maraković, 1996; Myerson et al., 2011).

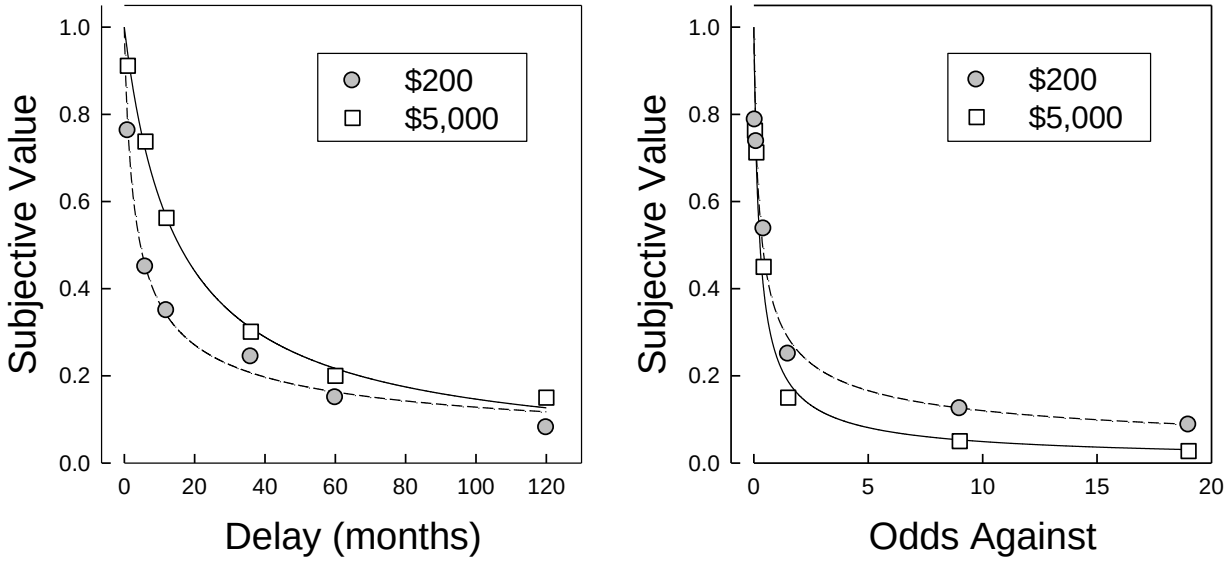

Figure 2. Example of the amount effects in delay and probability discounting. The subjective value of $200 and $5,000 rewards (expressed as a proportion of their nominal amounts) is plotted as a function of the time until their receipt (delay discounting, left panel) or odds against their receipt (probability discounting, right panel). The curved lines represent the best-fitting hyperboloid discounting functions (Equation 1). Notice that the effect of amount on the discounting of delayed rewards is opposite that on the discounting of probabilistic rewards. Data are from Experiment 2 of "Amount of reward has opposite effects on the discounting of delayed and probabilistic outcomes," by L. Green, J. Myerson, and P. Ostaszewski, 1999, *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* p. 423.

Results obtained with animal subjects stand in stark contrast to those reported with humans. Using adjusting-amount procedures, several animal delay discounting studies have failed to observe an amount effect. Richards et al. (1997, Experiment 3) studied rats' discounting of different amounts of delayed water. Although a small tendency for steeper discounting for the larger reinforcers (an effect opposite to what is typically observed in humans) was observed, this effect was not significant. Green et al. (2004) also failed to find an effect of amount on the degree of delay discounting of food reinforcers by pigeons and rats. In this study,

delays varied between 1 and 32 seconds, and the larger amounts varied between 5 and 32 pellets for pigeons and 5 and 20 pellets for rats. Rates of discounting were higher for pigeons than for rats, but no systematic effects of amount on the degree of discounting were observed in either species.

Calvert et al. (2010) assessed rats' degree of preference for different food and water reinforcers, and then compared the discounting rates of different amounts of each reinforcer, as well as the discounting rates of differentially preferred reinforcers (highly preferred vs. less-preferred reinforcers of the same amount). Consistent with previous findings, no systematic difference in degree of discounting as a function of the quantity (i.e., amount of reinforcer) was observed. In addition, there was no systematic difference in the degree of discounting as a function of the quality (i.e., differentially preferred reinforcers) of the reinforcer. Finally, Freeman, Nonnemacher, Green, Myerson, and Woolverton (2012) extended these findings to nonhuman primates using a similar procedure. Freeman et al. compared the rates at which rhesus monkeys discounted 10% and 20% concentrations of delayed sucrose and found no systematic differences in the discounting of the two sucrose concentrations.

Another set of studies used a concurrent-chains procedure to evaluate the effects of amount on the discounting of delayed reinforcers in animals. Unlike most procedures used in animal behavioral research, where the trials consist of a responding period followed by reinforcement, the trials in a concurrent-chains procedure consist of two consecutive responding periods followed by reinforcement. These two responding periods are called the initial (or choice) link and the terminal link. Typically, the initial link of a concurrent-chain consists of two response alternatives, each associated with identical, but independent VI schedules (e.g., two VI 30-s schedules running concurrently during the initial link). During the initial link, the

animal chooses which of the mutually exclusive terminal links – themselves usually associated with different delays or reinforcer amounts – it prefers to enter. Notice that, in the adjusting-amount procedures used in the studies described above, the subjects choose one of the reinforcer alternatives in an all-or-none fashion via a single response. In contrast, during the initial link of a concurrent-chains procedure, the subjects distribute their responses over both alternatives during a period of time (i.e., the VI schedule) in a way that reflects their preference for each of the terminal links (which are associated with different reinforcement schedules or amounts). This response allocation thus provides a richer assessment of the animals' preferences (Autor, 1960, 1969; Herrnstein, 1964).

Grace (1999) used a two-component concurrent-chains procedure, with each component in effect for half a session. In both components, the initial-links were associated with independent, concurrent variable-interval schedules (specifically, a *conc* VI-30 s VI-30 s). In the "small amount" component, the response keys were transilluminated with red light in the initial link, and both terminal links were associated with relatively brief access to food, whereas in the "large amount" component, the response keys were transilluminated with green light in the initial link and both terminal links were associated with access to food for 2.5 times longer than in the smaller amount component. The terminal links of both components were associated with different pairs of VI schedules across different experimental conditions (10 s and 20 s; 20 s and 10 s; 6 s and 24 s; and 24 s and 6 s). Sensitivity to terminal-link delay was evaluated by examining how response allocation in the initial link varied across conditions, with more extreme preference for the briefer terminal-link schedule taken as evidence of greater sensitivity to delay. Grace argued that, in human studies, participants' choices are more sensitive to delay the smaller the reinforcer amount, thereby resulting in steeper discounting curves for smaller amounts.

Accordingly, the goal of his study was to determine whether the amount of reinforcer would similarly affect the pigeons' sensitivity to delay. Results showed no systematic differences in the pigeons' sensitivity to delay between the "small amount" and "large amount" components. That is, there was no difference in delay sensitivity as a function of the amount of reinforcement.

Ong and White (2004) repeated Grace's (1999) study with modifications aimed at enhancing discrimination between the "small amount" and "large amount" components. Specifically, in their Experiment 1, Ong and White used a larger ratio between the two reinforcer durations (4.5-s vs. 1-s access to grain) and reversed the terminal-link delays between components so that the delay to the smaller and larger amounts was conditional on the color of the initial-link keys. Their results suggested that pigeons' delay sensitivity was greater for the larger amount, although this was not true in their Experiment 2 where they replicated the procedure used by Grace. More recently, Orduña, Valencia-Torres, Cruz, and Bouzas (2013) conducted a study with rats in which they replicated Ong and White's first experiment, and again found greater sensitivity to delay in the component with the larger reinforcer. It is important to note that the direction of this effect is the opposite of that typically observed with humans, whose sensitivity to delay is consistently greater with smaller amounts (i.e., smaller rewards are discounted more steeply than larger rewards).

Only Grace, Sargisson, and White (2012) have reported an effect of reinforcer amount in nonhuman animals (specifically, pigeons) that is consistent with that observed with human participants. Like Orduña et al. (2013) and Ong and White (2004), Grace et al. (2012) used a two-component concurrent-chains procedure, but in this case each terminal link was associated with a different amount of food (1-s vs. 4.5-s access to wheat). In the component in which the initial-link keys were red, the delay to the smaller amount of food in the terminal link was always

2 s and the delay to the larger amount of food was varied between 2 and 28 s across conditions. In the component in which the initial-link keys were green, the delay to the larger amount in the terminal link was always 28 s and the delay to the smaller amount was varied between 2 and 28 s across conditions. Grace et al. compared the rate at which preference for the larger reinforcer decreased as its delay increased across conditions in the red component with the rate at which preference for the smaller reinforcer decreased as its delay increased across conditions in the green component. They reported that relative preference for the larger amount, a measure of its relative value, decreased more slowly with increasing delay than did relative preference for the smaller reinforcer amount, which they interpreted as indicating steeper discounting of smaller rewards, a result similar to that observed with humans.

Taken together, these studies show a lack of a systematic effect of amount in nonhuman animals, a finding that stands in contrast to the discounting results obtained with humans. However, it may be noted that the one animal study that did obtain an amount effect consistent with that observed in humans (Grace et al., 2012) used a concurrent-chains procedure and, unlike the other concurrent-chains studies described above, it actually assessed discounting directly. For this reason, it is plausible that the different patterns of results obtained with humans and animals regarding an amount effect are not due to a species difference, but rather that the concurrent-chains procedures are more appropriate for revealing the occurrence of the amount effect in animals than the adjusting-amount procedures.

Preference Reversals

The phenomenon of preference reversals occurs when people prefer a larger-later reward to a smaller-sooner reward when both outcomes are somewhat distant in the future, and reverse their preference as the time to the receipt of the smaller-sooner reward approaches. For example,

one might prefer to receive $1,000 in 5 years rather than $500 in 4 years, but prefer to receive the $500 in one month rather than $1,000 in a year and one month.

Figure 3 illustrates a preference reversal situation. The heights of the bars represent the amounts of two rewards, and the curved lines depict their subjective (i.e., discounted) values as predicted by the hyperbolic model (Equation 1 with s = 1.0). The likelihood of choosing a particular alternative depends on the subjective values of the two rewards at the point in time. For example, at T_1, choice of the larger-later reward is more likely, whereas later in time, at T_2, choice of the smaller-sooner reward becomes more likely.

Preference reversals are a well-described phenomenon that occurs in both humans and animals (e.g., Ainslie & Herrnstein, 1981; Green & Estle, 2003; Green, Fisher, Perlow, & Sherman, 1981; Green, Fristoe, and Myerson, 1994; Kirby & Herrnstein, 1995; Rodriguez & Logue, 1988). For example, in Green et al. (1981), pigeons chose between a smaller-sooner reinforcer and a larger-later reinforcer. When the smaller amount was available after 28 seconds and the larger after 32 seconds, all the pigeons strongly preferred the larger reinforcer. However, when the smaller reinforcer was available after 2 seconds and the larger after 6 seconds (note the same 4-second difference between the time when the smaller reinforcer could be received and when the larger reinforcer could be received), all the pigeons overwhelmingly preferred the smaller amount.

Green, Fristoe, and Myerson (1994) observed preference reversals in humans using a similar procedure. For example, most participants chose $50 in one year and six months over $20 in one year. However, when the same choice was offered much closer in time to when the $20 would become available, the proportion of participants who now preferred the $50

decreased. This preference reversal was observed using several delays to the smaller reward, inter-reward delays, and pairs of amounts.

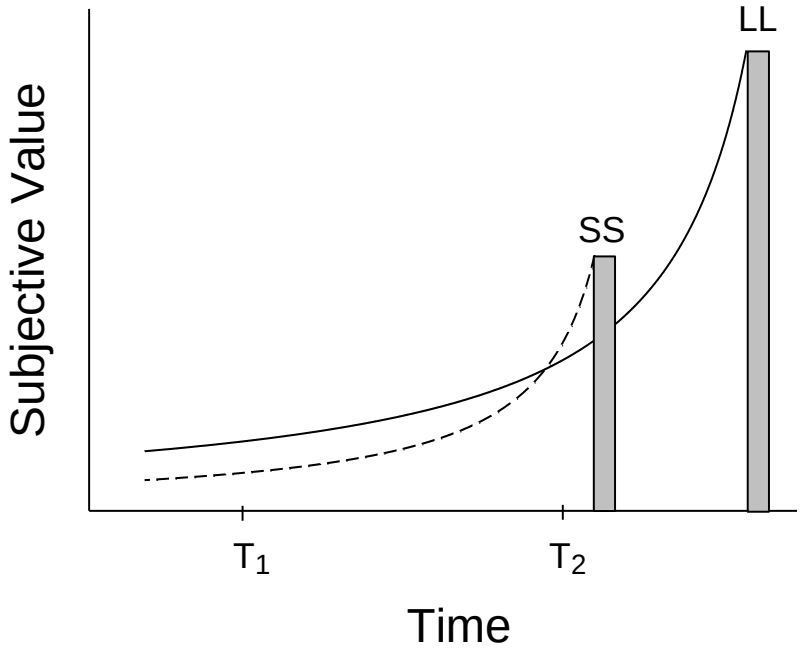

Figure 3. Choice between a smaller-sooner (SS) reward and a larger-later (LL) reward. The curved lines show how subjective value changes as a function of time to receiving the rewards according to the hyperbolic model of discounting. The cross-over indicates the point of preference reversal. The heights of the bars represent the nominal amount of reward.

In the case of probabilistic outcomes, preference reversals are better known as the Allais Paradox (Allais, 1953) and have thus far been studied only with human subjects. In his study, Allais observed that most participants preferred receiving $1M for sure rather than $2M with an 80% chance, but would reverse their preference if the same rewards were associated with 5% and 4% chances, respectively (note that the expected value ratio between the alternatives is the same in both situations, as they share the same common [.05] multiplier: 100% ∗ .05 = 5%, and 80% ∗ .05 = 4%). Kahneman and Tversky (1979) observed the same phenomenon and termed it the 'certainty effect', given that individuals seem to overweight the value of certain (or at least

highly likely) outcomes. As a result, participants make more risk-averse choices when the smaller reward is certain and more risk-seeking choices when both rewards are unlikely.

Morris (2010) used an adjusting-amount procedure to study how participants chose between a larger amount ($250, $50,000, and $2,000,000 in different conditions) associated with different probabilities of receipt (.80, .50, .25, .10, and .05 in different conditions), and a smaller, but certain amount. He then added common multipliers (0.5, 0.2, 0.1, and 0.05) to the probabilities of both outcomes and repeated the procedure, thus obtaining discounting functions in situations in which both rewards were probabilistic. Results showed that preference reversals only occurred with the lower common multipliers (0.1 and 0.05), where participants came to make more risk-seeking choices.

Probability Discounting in Animals

When comparing discounting between humans and animals – whether it relates to the mathematical model's parameters, the amount effect, preference reversals, etc. – one aspect that stands out is the paucity of research on the discounting of probabilistic reinforcers by animals.

Mobini, Chiang, Ho, Bradshaw, and Szabadi (2000) compared the behavior of normal rats to that of rats with destroyed 5-HTergic pathways (believed to be involved in self-control behavior) with both delay and probability discounting tasks. In the probability discounting task, rats chose between a smaller, certain reinforcer and a larger, but probabilistic reinforcer (with *p* varying from 0.88 to 0.08). Each session consisted of 60 trials (50 forced trials – 25 associated with the smaller, certain reinforcer and 25 associated with the larger, probabilistic reinforcer – and 10 free-choice trials; the high percentage of forced trials was intended to ensure familiarity with the probabilities and to minimize differences in exposure to each alternative). The dependent variable was the proportion of choices of the larger, probabilistic reinforcer on the

free-choice trials. Results showed that percent choice of the larger reinforcer decreased as the odds against receiving it increased, and did so at the same rate for both groups of rats. Although these findings are consistent with what is found in probability discounting studies with humans, the study did not obtain indifference points at each probability level (for example, by successively adjusting the smaller amount according to the rats' choices). Rather, the authors simply assessed the level of preference at each probability studied. Mobini et al. (2002) replicated the findings with rats with orbitofrontal cortex lesions using an identical procedure. Again, results showed a decrease in preference for the larger reinforcer as the odds against its receipt increased. In this case, however, the lesioned rats showed a greater preference for the smaller, certain outcome than did the normal rats.

Wilhelm and Mitchell (2008) used a procedure similar to the one developed by Richards et al. (1997), described earlier. Wilhelm and Mitchell had rats choose between two levers, one associated with a smaller, certain reinforcer and another associated with a larger, probabilistic reinforcer. The amount of the smaller reinforcer was adjusted throughout the session based on the rats' previous choices. Whenever a rat chose the same lever on two consecutive trials, a forced trial followed in which the rat had to press the opposite lever. Results showed that as the odds against receiving the reinforcer increased, the subjective value of that reinforcer decreased, a finding similar to what has been observed with humans.

Despite these initial efforts, two variables may have affected the results in all three studies (Mobini et al., 2000, 2002; Wilhelm & Mitchell, 2008). First, given that the larger outcome was probabilistic, the probability actually experienced within a given session often varied substantially from the programmed probability. For example, in Mobini et al. (2000, 2002), each session included only 10 free-choice trials, and the programmed probability of

obtaining the larger reinforcer was as low as 0.08. Thus, the experienced reinforcement probabilities often differed greatly from the programmed probabilities. Secondly, forced trials serve the function of ensuring exposure to both outcomes throughout the session. This contingency is relatively straightforward in a delay discounting task, but not in a probability discounting task. In the latter case, on a probabilistic forced trial, the rats had no way of experiencing the contingencies associated with that lever – how does one expose an organism to a 0.25 chance of receiving a reinforcer on a single trial? As a consequence, the outcome of probabilistic forced trials could potentially have affected subsequent choices.

Recently, Green, Myerson, and Calvert (2010), using an adjusting-amount procedure to obtain a discounting function, had pigeons choose between a smaller reinforcer that could be received after one response and a larger reinforcer that could be received after a number of responses that would vary across conditions according to the probability being tested (e.g., in the 0.10 probability condition, an average of ten pecks – or variable ratio [VR] 10 – was required to produce the larger reinforcer). Results showed that the pigeons' discounting was well described by the hyperbolic function (i.e., Equation 1 with *s* set equal to 1.0). However, this procedure is dissimilar to the one typically used in human studies or in Wilhelm and Mitchell's study (2008), in which trials are presented in the form of a one-shot chance of receiving the outcome (i.e., on any given trial, the subject does or does not receive the outcome). In contrast, a VR schedule simulates a repeated-gambles-type situation (i.e., the outcome is received on every trial, albeit after a different number of responses). Furthermore, results showed that, with the use of the VR schedules, choice appeared to be controlled by the delay to reinforcement, rather than the odds against receiving the reinforcer. In other words, the discounting shown by pigeons was well accounted for by the time it took them to complete the VR schedule requirements.

Given how little research has been conducted on probability discounting with nonhuman animals, it is important to determine whether a nonhuman species would show reliable probability discounting using one-shot chance choice scenarios in which the probabilities experienced by the animals equals those programmed. A positive finding would then allow researchers to explore other variables, such as whether an amount effect or a certainty effect would be observed, and allow for a comparison of the results with those obtained with human participants.

Concurrent-Chains Procedures and Probability Discounting

The main purpose of the present work was to determine whether pigeons would show discounting of a probabilistic food reinforcer and whether the results would be well described by the hyperbolic discounting function (i.e., Equation 1 with *s* set equal to 1.0).

The starting point to designing a procedure was that it would have to address the shortcomings of the Wilhelm and Mitchell (2008), Mobini et al. (2000, 2002), and Green et al. (2010) studies. Specifically, the procedure would have to present the choices in a one-shot chance format, ensure that the probabilities experienced by the animals would equal those assigned to each condition, expose the pigeons to the experimental contingencies without resorting to forced trials, and equalize the time from the choice to the receipt of the outcome.

All these objectives are fulfilled using a concurrent-chains procedure (see Figure 4). In this procedure, the initial link is associated with a single non-independent VI 30-s schedule (Alsop & Davison, 1986; Stubbs & Pliskoff, 1969). During the initial link, the pigeon allocates its responses across the two, concurrently available white keys. When the VI 30-s times out, the computer pseudo-randomly assigns entry into one of the two mutually exclusive terminal links. The pigeon then must respond on that effective initial-link key in order to gain entrance into its

terminal link. Each terminal link is associated with a different outcome and after the terminal link ends, there is an inter-trial interval after which the initial link is reinstated.

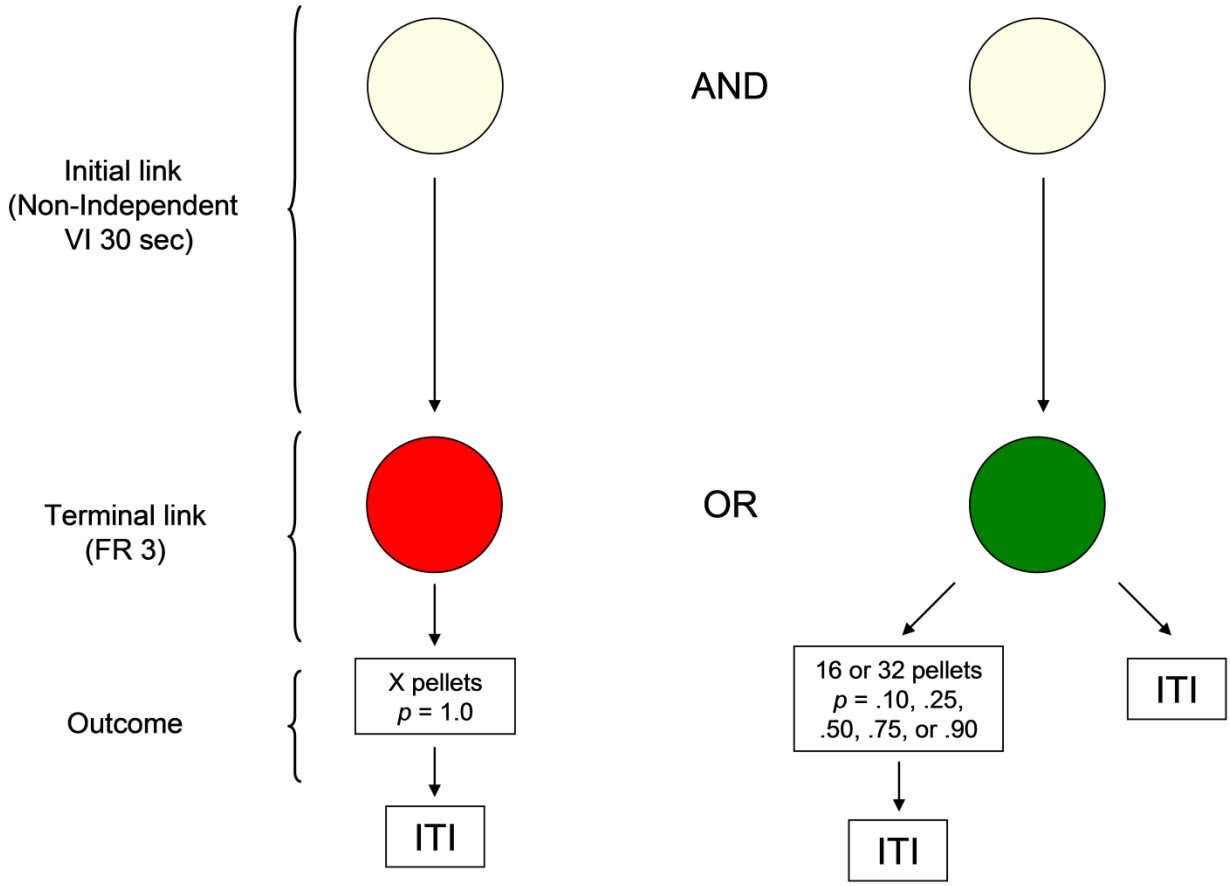

Figure 4. Diagram of the concurrent-chains procedure used in Experiment 1.

This concurrent-chains procedure ensured that the pigeons experienced the exact probabilities programmed for each of the conditions by controlling the number of times each terminal link was experienced. Specifically, each session consisted of 40 trials, half of which resulted in the smaller, certain reinforcer (associated with the left terminal link in Figure 4), and half of which resulted in the larger, probabilistic reinforcer (associated with the right terminal link in Figure 4). In the case of probabilistic (right terminal link) trials, the computer pseudo-

randomly selected whether the trial would be reinforced or not. For example, in the $p = 0.25$ condition, of the 20 times the pigeon experienced the right terminal link in a session, five trials resulted in reinforcement and 15 trials were not reinforced. Note that this procedure represents a one-shot chance choice scenario (i.e., on a probabilistic trial, the pigeon either received the reinforcer or not). Additionally, the use of the non-independent VI schedule in the initial link ensured equal exposure to the certain and the probabilistic terminal-link outcomes, and as a consequence there was no need to resort to forced trials. Finally, the procedure equalized the time from the choice (i.e., the response that ended the initial link and initiated the terminal link) to the receipt of the reinforcer, therefore ensuring that the probability of, rather than the time to the reinforcer controlled behavior.

It is important to note that while the use of the non-independent VI schedule in the initial link has the significant advantage of equalizing the number of times each terminal link is presented, thereby ensuring that the experienced probabilities equal those programmed, it does have the undesired effect of potentially reducing the pigeons' preference for one or the other terminal-link outcomes. For example, a pigeon that might overwhelmingly prefer the smaller, certain reinforcer (associated with the left key) will come to peck the right initial-link key more than it might have otherwise because the procedure requires responding on that key and entry into its associated terminal link before the session is allowed to proceed and the pigeon can gain entry into the more-preferred left terminal link on subsequent trials. Because the order of the trials is assigned pseudo-randomly, the pigeon must respond on both keys, even in cases where one of the outcomes is strongly dispreferred. This procedural limitation will be addressed in the General Discussion.

Based on the relative preferences during the initial link, the smaller amount was adjusted until an indifference point was reached (i.e., relative choice between the two terminal links was approximately .50). This novel procedure, in effect, combines the concurrent-chains and the adjusting-amount procedures.

As noted above, probability discounting studies using human subjects consistently report the occurrence of an amount effect. However, the direction of the amount effect is opposite that observed in studies of delay discounting: With probability discounting, rate of discounting increases as the amount of the probabilistic outcome increases (e.g., Green et al., 1999). A second goal of Experiments 1 and 2 was to determine whether an amount effect would be observed when the reinforcers being discounted were probabilistic. To that end, we introduced an amount manipulation in both experiments (the larger reinforcer was 16 and 32 food pellets in different phases). If the results from these two experiments show orderly discounting functions, well described by the hyperbolic function, and yet fail to show an amount effect, such a finding would be consistent with the view that the amount effect represents a species difference.

An additional goal of Experiment 2 was to test for the occurrence of the certainty effect. To that end, we multiplied the probabilities associated with both the smaller and the larger reinforcers by different factors: 1.0 (in which case the smaller reinforcer was certain), 0.75, and 0.25 (in these latter two cases, both reinforcers were probabilistic, but the relative likelihood between the two outcomes remained the same). If the certainty effect were to occur, that is, if pigeons overweight the value of certain outcomes, we would expect to observe steepest discounting in the 1.0 multiplier condition and shallowest discounting in the 0.25 multiplier condition.

Given how different the procedure developed for this study was from the typical procedure used in delay discounting studies with animals, it was deemed necessary to include a third experiment to investigate whether the results found with the typical adjusting-amount procedure with animals would also be observed under the current procedure. Accordingly, Experiment 3 used the same concurrent-chains and adjusting-amount procedure as used in Experiments 1 and 2, in which adjustments to the smaller amount were made between sessions based on preferences demonstrated within sessions. However, instead of choosing between probabilistic reinforcers, the pigeons chose between a smaller, immediate reinforcer and a larger, delayed reinforcer. In the first phase of the experiment, pigeons were studied at five different delays to a larger, delayed reinforcer (32 food pellets) so as to plot out individual discounting functions and evaluate whether the hyperbola would provide a good description of the data.

The second phase of Experiment 3 was designed as a systematic replication of the first phase that would allow us to evaluate whether an amount effect was observed when the amount of the delayed reinforcer was changed. The same pigeons were studied in the second phase using the same procedure and delays as in the first phase, but with the amount of the delayed reinforcer reduced by half (from 32 pellets in Phase 1 to 16 pellets in Phase 2). If the degree of discounting increased when the amount of the delayed reinforcer was reduced to 16 pellets, such a finding would be evidence for an amount effect similar to that observed with humans.

Experiment 1

Method

Subjects

Eight experimentally naïve White Carneau pigeons (*Columba livia*) were used. The pigeons were maintained at 85% of their free-feeding weights by providing post-session feeding

when necessary. The pigeons were housed in individual home cages where they had continuous access to water and grit and were maintained on a 12:12-h light:dark cycle.

Apparatus

Two experimental chambers (Med Associates, Inc.), each measuring 29 cm long by 25 cm wide by 28.5 cm high, were located within sound- and light-attenuating enclosures equipped with ventilation fans. Two response keys, spaced 16 cm apart, center to center, were mounted on the front panel of the chamber. The keys were located 23.5 cm above the grid floor and 3.5 cm from the side walls of the chamber, and could be transilluminated with white, red, and green lights. A clicker was used to provide auditory feedback for all responses made during the trial. A food magazine was mounted on the center of the panel, 4 cm above the grid floor, equipped with a 7-W white light that was illuminated during reinforcement and a photobeam to detect head entry. A pellet dispenser (Med Associates, Inc.), mounted behind the front panel, delivered 20-mg precision food pellets (TestDiet®) at the rate of one pellet every 0.3 s. A 7-W houselight was mounted centrally on the ceiling of the chamber. Med-PC™ software (Med-Associates, Inc.) was used to control experimental events and record responses.

Procedure

Pigeons were trained to peck illuminated response keys to receive food reinforcement using an auto-shaping procedure (Brown & Jenkins, 1968). Experimental sessions began as soon as they showed reliable key-pecking behavior.

The experiment consisted of ten experimental conditions: two different amounts for the larger, probabilistic reinforcer (16 and 32 food pellets), each studied at five probabilities (0.1, 0.25, 0.5, 0.75, and 0.9). Half of the pigeons completed all 16-pellet conditions first before running in the 32-pellet conditions, whereas the other half completed the 32-pellet conditions

first. Within each amount, all pigeons started with the 0.5 probability condition. The other four probabilities were run in different orders for each pigeon. (See Appendix A for the order in which each pigeon experienced the experimental conditions.)

A concurrent-chains procedure was used (see Figure 4 for a diagram of the procedure used in Experiment 1). Sessions consisted of 40 trials, 20 of which resulted in entry into the left terminal link and 20 resulted in entry into the right terminal link. At initial-link trial onset, the houselight turned on and both the left and right keys were illuminated with white light. The initial link was associated with a single non-independent VI 30-s schedule. The values used for the VI intervals were derived using the exponential progression method described in Fleshler and Hoffman (1962). When the VI 30-s timed out, the computer pseudo-randomly determined on which initial-link key the pigeon had to respond in order to gain entrance into a terminal link.

In the terminal link, red and green keys were associated with either the smaller, certain reinforcer or the larger, probabilistic reinforcer. For half of the pigeons, the smaller, certain reinforcer was associated with the left, red key, and the larger, probabilistic reinforcer was associated with the right, green key. For the other half of the pigeons, the smaller, certain reinforcer was associated with the right, green key, and the larger, probabilistic reinforcer was associated with the left, red key. However, for ease of exposition, all conditions will be described according to the former arrangement.

A 2-s changeover delay (COD) was used in the initial link, requiring that a minimum amount of time (2 s) had to elapse between a changeover from responding on one key to responding on the other key before entry into the terminal link. For example, on a smaller-certain trial, if the pigeon were pecking on the side associated with the larger, probabilistic outcome after the VI had timed out, it would have to switch to the other side and continue

responding there for a period of 2 seconds in order to proceed to the respective terminal link. Without a COD, pigeons often come to constantly switch between both keys (e.g., Herrnstein, 1961; Shahan & Lattal, 1998; Shull & Pliskoff, 1967).

On smaller-certain trials, once the VI in the initial link had timed out (and the COD was satisfied), a peck on the left white key turned both white keys off and turned the left red key on. After three pecks (FR 3), the red key turned off, the food magazine light turned on, and the small reinforcer amount was delivered.

On larger-probabilistic trials, once the VI had timed out (and the COD was satisfied), a peck on the right white key turned both white keys off and turned the right green key on. The reinforced trials were pseudo-randomly selected (the number of probabilistic trials that were reinforced in a given session varied from 2 in the 0.1 probability conditions, to 18 in the 0.9 probability conditions). If a trial was to end in reinforcement, then the third peck on the green key (FR 3) turned it off, turned the food magazine light on, and delivered the larger reinforcer amount (16 or 32 pellets). If a trial was not to end in reinforcement, then the third peck on the green key would turn it off and initiate the inter-trial interval (ITI), during which all lights and stimuli were turned off. On all reinforced trials (certain or probabilistic), after the last food pellet was delivered, the magazine light remained on until 3 s had elapsed without the pigeon interrupting the magazine photobeam, after which the ITI began. The time from the onset of a terminal link to the onset of the next initial-link trial was held constant at 45 s. This was achieved by allowing the ITI to vary based on the time spent in the terminal link and the time spent eating the pellets from the magazine. Following the ITI, the next trial began.

In the first session of each condition, the pigeons chose between the larger reinforcer (16 or 32 pellets) and a smaller amount half that of the larger reinforcer (i.e., 8 or 16 pellets). The

pigeons' preference for the certain terminal-link outcome was assessed via the relative number of pecks made on the left white key during the initial link (the initial-link key associated with the smaller, certain reinforcer) over the course of the entire session. If the number of pecks made on the left white key represented more than 55% of the total number of initial-link pecks made during the session, the pigeon was said to prefer the smaller, certain outcome. If that number of pecks represented less than 45% of the total number of initial-link pecks, the pigeon was said to prefer the larger, probabilistic outcome. A relative number of responses between 45 and 55% of the initial-link total was considered to represent indifference between the two terminal-link outcomes.

In each condition, an adjusting-amount procedure was used to obtain an estimate of the amount of the certain reinforcer that was equivalent in value to the probabilistic reinforcer (for details, see Du et al., 2002). If the pigeon preferred the certain reinforcer, the amount of the smaller reinforcer was decreased; if the pigeon preferred the probabilistic reinforcer, the amount of the smaller reinforcer was increased; if the pigeon showed no preference, the condition was terminated and that smaller amount was considered to be an estimate of the subjective value of the larger, probabilistic reinforcer.

The size of the adjustment (i.e., the decrease or increase in the amount of the certain reinforcer) decreased throughout the condition. The first adjustment was half of the difference between the certain and the probabilistic reinforcers, and each subsequent adjustment was half that of the preceding adjustment, down to a 2-pellet adjustment. For example, in the condition in which the pigeon chose between 8 certain pellets and 16 pellets with a 0.75 probability, if the pigeon preferred the 16 pellets, then the smaller reinforcer would be increased to 12 pellets. If then the pigeon showed a preference for the 12 pellets, the amount of the smaller reinforcer

would be decreased to 10 pellets (the final, 2-pellet adjustment). At this point, the preference shown by the pigeon determined the final subjective value for that condition. If the pigeon preferred the 10 pellets, the final subjective value was estimated to be 9; if the pigeon preferred the 16 pellets, the final subjective value was estimated to be 11; and if the pigeon was indifferent between 10 and 16, the final subjective value was estimated to be 10. The condition ended, then, when the pigeon was indifferent between the two amounts (i.e., relative number of responses in the initial link was between 45 and 55%), or when preference was stable (see below) at the 2-pellet adjustment point.

Several conditions had to be met for the pigeon's behavior to be considered stable. First, a minimum of seven sessions were run at each adjusting amount. Second, the relative number of responses made during the initial link had to be within one of three ranges (< 45%, 45-55%, or > 55%) for each of the final five sessions. Finally, the last three sessions could not show a trend (with the exceptions of a trend towards 0% when preference was below 45% or towards 100% when preference was above 55%). The mean number of sessions across all pigeons was 29.9 (*SD* = 13.9; range = 7-81) for the 16-pellet conditions and 30.7 (*SD* = 15.2; range = 7-66) for the 32-pellet conditions (see Appendix B for the number of sessions for each pigeon on each condition).

Results and Discussion

Figure 5 shows the relative subjective value of the probabilistic reinforcer (i.e., the amount of the certain reinforcer at the indifference point as a proportion of the amount of the probabilistic reinforcer) plotted as a function of odds against for each pigeon and for the group means (bottom right panel). Filled symbols represent data from the 16-pellet conditions, and open symbols represent data from the 32-pellet conditions.

For all pigeons, it is clear that, as the odds against receiving a reinforcer increased, the subjective value of that reinforcer decreased. A simple hyperbola (Equation 1 with *s* set equal to 1.0) was used to fit the data[1]. The obtained individual fits were generally good, with a median R^2 of .87 and a mean of .78. Table 1 presents the proportion of variance accounted for (R^2) and the discounting rate parameter (*b*) for each pigeon and for the group means for each amount.

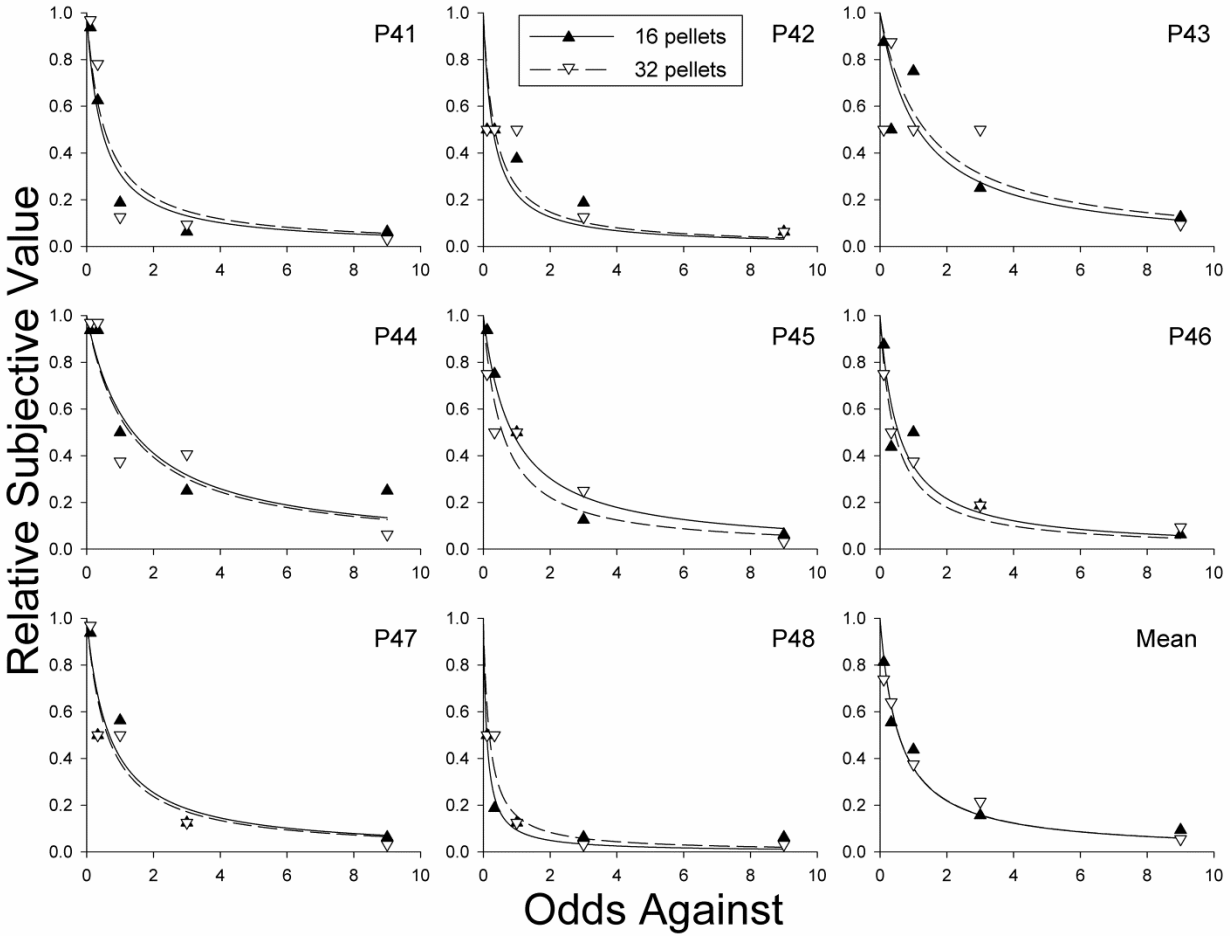

Figure 5. Relative subjective value of the 16- and 32-pellet reinforcers plotted as a function of odds against. Symbols represent the estimated indifference points, and curves represent the best-fitting hyperbolic discounting function for each pigeon and for the group means. The 16-pellet amount is represented by solid curves and filled triangles; the 32-pellet amount is represented by dashed curves and open inverted triangles.

[1] The data were also fit using Equation 1 while allowing the *s* parameter to vary. In four (out of 16) cases the *s* parameter was significantly less than 1.0: P42 at 16 pellets and P42, P43, and P46 at 32 pellets. In no case was *s* significantly greater than 1.0.

Table 1. Proportions of variance accounted for (R^2), discounting rate parameters (b), and root mean square error (RMSE) for the 16- and 32-pellet discounting functions for each pigeon and for the mean in Experiment 1.

Pigeon	Amount	R^2	b	RMSE
41	16	.93	2.22	0.090
	32	.87	1.87	0.142
42	16	.44	3.48	0.130
	32	.37	2.906	0.159
43	16	.69	0.88	0.158
	32	.25	0.74	0.214
44	16	.91	0.72	0.092
	32	.87	0.77	0.129
45	16	.97	1.15	0.055
	32	.83	1.76	0.102
46	16	.85	1.81	0.108
	32	.93	2.30	0.059
47	16	.87	1.47	0.113
	32	.90	1.61	0.104
48	16	.95	9.69	0.038
	32	.84	5.49	0.087
Mean	16	.96	1.79	0.051
	32	.96	1.77	0.051

In addition, Table 1 also presents the root mean square error (RMSE) for fits of the simple hyperbola to the data from each subject in each amount condition. As Johnson and Bickel (2008) noted, the R^2s for fits of hyperbolic discounting functions tend to be correlated with estimates of the b parameter because R^2 depends on the ratio of the variance in the residuals to the variance in the data, and steep discounting tends to be associated with greater variance in the data than shallow discounting. The RMSE does not have this property because it is equivalent to the standard deviation of the residuals and is independent of the variance in the data. It also is independent of the number and range of the delays or odds against studied, and if the data are expressed in proportions (relative subjective value), it is independent of the amount

of the reward, as well. Thus, the RMSE, which may be thought of as a weighted average deviation from predictions, provides a good basis for comparing fits for different subjects as well as different conditions and studies.

Visual inspection of Figure 5 suggests that there are no systematic differences between the degrees of discounting of the two probabilistic food amounts. Indeed, a *t*-test showed no significant difference between the logarithms of the *b* values for the 16- and 32-pellet amounts, $t(14) = 0.09$, $p = .929$.

The degree of discounting of the 16- and 32-pellet amounts also was evaluated by calculating the area under the curve (AuC). The AuC measure (Myerson, Green, & Warusawitharana, 2001) is calculated based on the obtained indifference points rather than a fitted curve, and thus is a theoretically neutral measure. To calculate the AuC, one first normalizes the values on both axes, that is, divides each value of odds against by its maximum (in this case, the maximum value of the odds against was 9) and divides the estimated subjective value obtained at each probability by its respective nominal amount (i.e., 16 or 32 food pellets). This way, the AuC can vary between 0.0 (maximal discounting) and 1.0 (no discounting). Figure 6 shows the AuCs for each pigeon and the group means for both probabilistic amounts. Consistent with what was seen in Figure 5, no systematic differences between the degrees of discounting of the two amounts are apparent. Again, a *t*-test revealed no statistically significant difference between the AuCs for the 16- and 32-pellet conditions, $t(14) = 0.15$, $p = .886$.

The results of Experiment 1 clearly show that pigeons discounted probabilistic reinforcers in a fashion similar to that seen in delay discounting studies. Also, the data were well described by the hyperbolic discounting model (Equation 1 with *s* set equal to 1.0). These findings indicate that the present procedure, which combines the concurrent-chains and the

adjusting-amount procedures, is a valid technique in the study of probability discounting with animals.

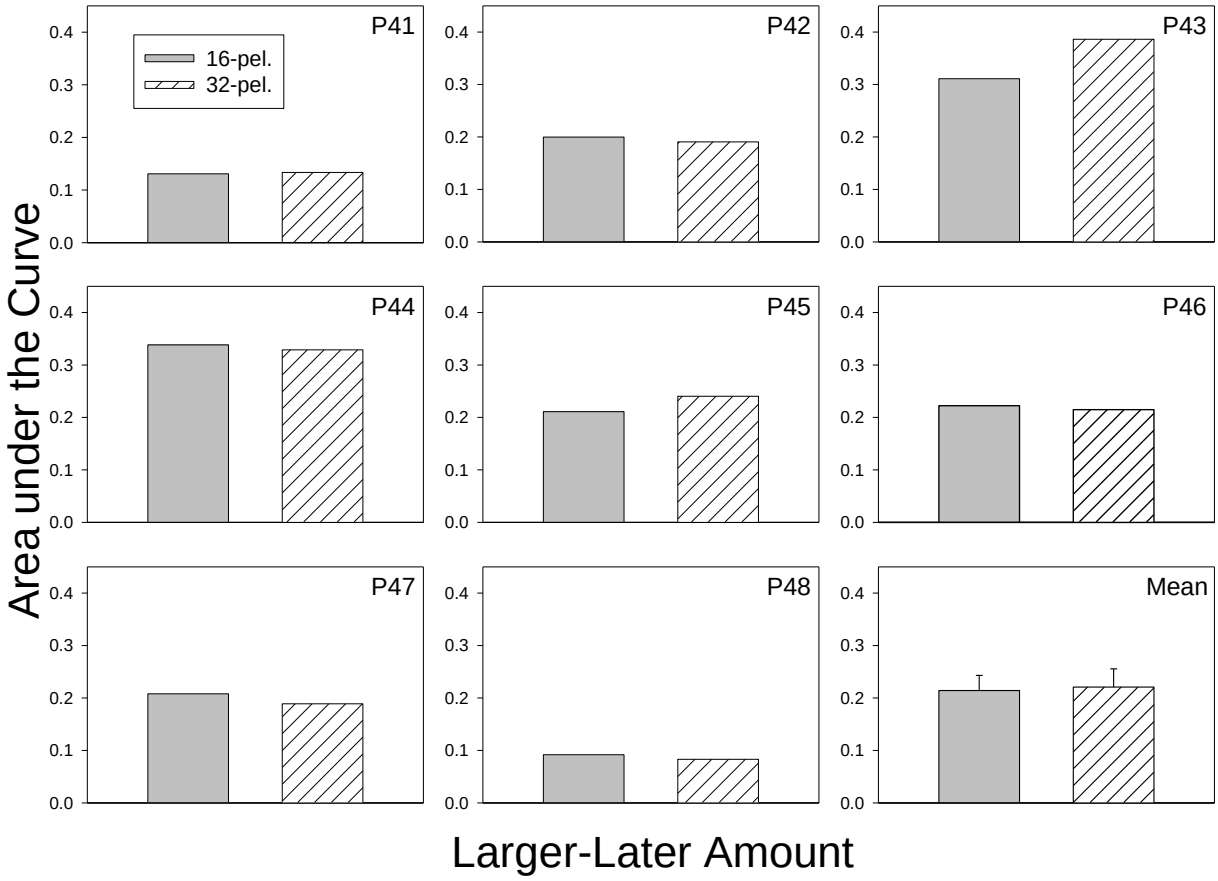

Figure 6. Area under the Curve for the 16- and 32-pellet conditions for each pigeon and for the group means. For the group means (bottom right panel), error bars represent the standard error of the mean.

The results also showed that, regardless of whether one uses AuC or *b* parameter estimates, there were no significant differences between the discounting of 16 and 32 food pellets. In other words, no amount effect was observed, a result consistent with most animal delay discounting studies and inconsistent with what is typically observed in human discounting studies. Furthermore, these results indicate that the lack of an amount effect can occur in

animals using a concurrent-chains procedure, and therefore is not exclusive to adjusting-amount procedures (cf. Grace et al., 2012).

Experiment 2

In Experiment 1, the smaller outcome was always associated with a probability of 1.0 (i.e., it was certain). In studies involving probabilistic rewards, human participants often show a bias for certain rewards – they often will choose a certain reward over a probabilistic one even when the probabilistic reward has greater expected value (i.e., the certainty effect; Kahneman & Tversky, 1979). In Experiment 2, we tested whether pigeons would show similar choice biases. Accordingly, we multiplied the probabilities associated with each reinforcer (1.0 for the smaller amount; 0.2, 0.4, 0.6, and 0.8 for the larger amount) by three different multipliers: 1.0 (in this case, the smaller amount was still certain), 0.75, and 0.25. If the pigeons, like humans, show a certainty effect, thus overweighting the value of certain outcomes (i.e., the smaller amount in the 1.0 multiplier conditions), we would observe steeper discounting of the larger reinforcer in the 1.0 multiplier conditions than in the 0.75 and the 0.25 multiplier conditions. In addition, we again tested for an amount effect by using two different standard amounts (16 and 32 pellets).

Method

Subjects and Apparatus

The same eight pigeons and two experimental chambers used in Experiment 1 were used in Experiment 2. Pigeon 47 was euthanized due to health concerns and completed only the first half of the experiment (the 16-pellet reinforcer conditions). Pigeon 43 did not complete the 1.0 multiplier conditions at 32 pellets.

Procedure

The structure of the trials and sessions, as well as the method for assessing the points of indifference, were the same as those described in Experiment 1.

The experiment consisted of 24 experimental conditions: two different amounts for the larger, less probable reinforcer (16 and 32 food pellets), each run at four probabilities (0.2, 0.4, 0.6, and 0.8), each of which, in turn, was run at three multipliers (1.0, 0.75, and 0.25). For each condition, the probabilities associated with the smaller and larger reinforcers were determined by multiplying the initial probabilities (1.0 for the smaller reinforcer; 0.2, 0.4, 0.6, and 0.8 for the larger reinforcer) by the three multipliers.

For example, in the condition involving the 0.2 probability of the larger reinforcer and the 0.25 multiplier, the smaller, more-probable reinforcer was associated with a chance of 100% x .25 = 25% (i.e., 5 of 20 daily trials in the smaller, more-probable terminal link ended with reinforcement) and the larger, less-probable reinforcer was associated with a chance of 20% x .25 = 5% (i.e., only 1 of its 20 daily trials ended with reinforcement). Note that, as in Experiment 1, for the conditions using the 1.0 multiplier, the smaller reinforcer was certain. Table 2 shows the probabilities associated with each outcome for every condition.

All pigeons completed the 16-pellet conditions before running in the 32-pellet conditions (see Appendix C for the order in which each pigeon experienced the conditions). The mean number of sessions was 28.9 (*SD* = 13.9; range = 7-82) for the 16-pellet conditions and 28.7 (*SD* = 17.6; range = 7-88) for the 32-pellet conditions (see Appendix D for the number of sessions for each pigeons on each condition).

Table 2. Probabilities associated with the larger reinforcer for every condition in Experiment 2. The probability of the smaller reinforcer is always equal to the multiplier.

	Multiplier		
Probability	**0.25**	**0.75**	**1.0**
0.2	0.05	0.15	0.2
0.4	0.10	0.30	0.4
0.6	0.15	0.45	0.6
0.8	0.20	0.60	0.8

Results and Discussion

Figure 7 shows the subjective value of the 16-pellet probabilistic reinforcer plotted as a function of the relative odds against its receipt (the odds against values were normalized so that all three multipliers could be compared directly; these values were obtained by calculating, for each condition: [(odds against less probable outcome - odds against more probable outcome) ∗multiplier]). All three multipliers are represented in each panel for each pigeon and the group means (bottom right panel). Figure 8 shows the same results for the 32-pellet conditions.

In both figures and for all pigeons, it is clear that, with a few exceptions, the subjective value of the larger reinforcer decreased as the relative odds against receiving that reinforcer increased. A simple hyperbola (Equation 1 with *s* set equal to 1.0) was again used to fit the data[2]. The obtained individual fits were generally good, with a median R^2 of .83 and a mean of .70 across all conditions for both amounts. Table 3 presents the estimates of the R^2 values, the discounting rate parameter (*b*), and the RMSE values for each pigeon and for the group means for all conditions.

[2] The data were also fit using Equation 1 while allowing the *s* parameter to vary. In only four (out of 44) cases was the *s* parameter significantly less than 1.0: P43 and P48 at 16 pellets for multiplier 1.0, and P43 at 32 pellets for multipliers 0.25 and 0.75. In no case was *s* significantly greater than 1.0.

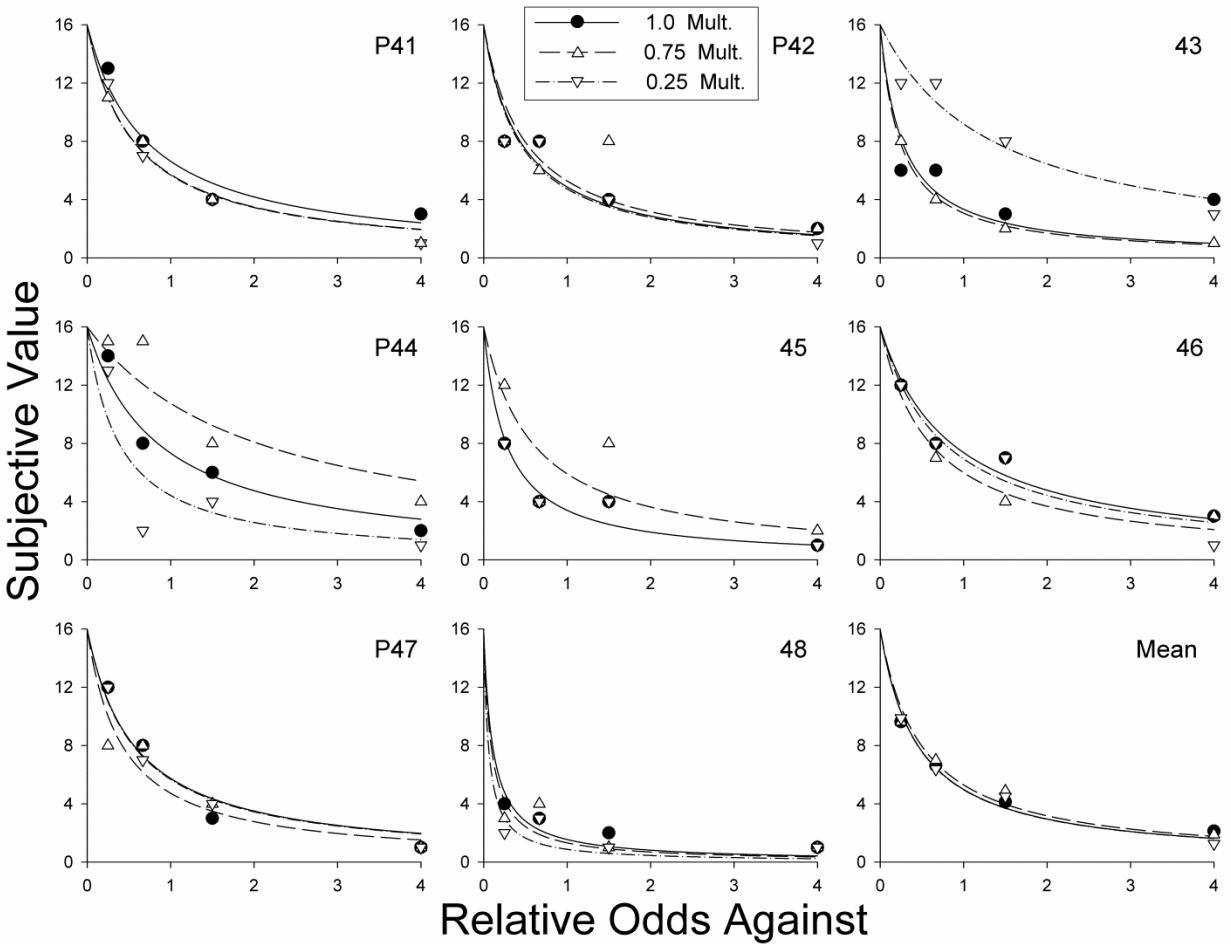

Figure 7. Subjective value of the 16-pellet reinforcers at each multiplier plotted as a function of relative odds against. Symbols represent the estimated indifference points, and curves represent the best-fitting hyperbolic discounting function for each pigeon and for the group means. The 1.0 multiplier is represented by solid curves and filled circles; the 0.75 multiplier is represented by dashed curves and open triangles; and the 0.25 multiplier is represented by dash-dotted curves and open inverted triangles.

Visual inspection of the discounting functions for the three multiplier conditions indicates that there are no systematic differences across individual pigeons, or at the group mean level. This can be seen more clearly in Figure 9, which plots the obtained estimates of the *b* parameter on a logarithmic scale for all subjects from all conditions. This figure also shows that there are no clear differences in the degree of discounting between the two amounts studied. The logarithms of the *b* values were analyzed using a two-factor, repeated measures ANOVA (2

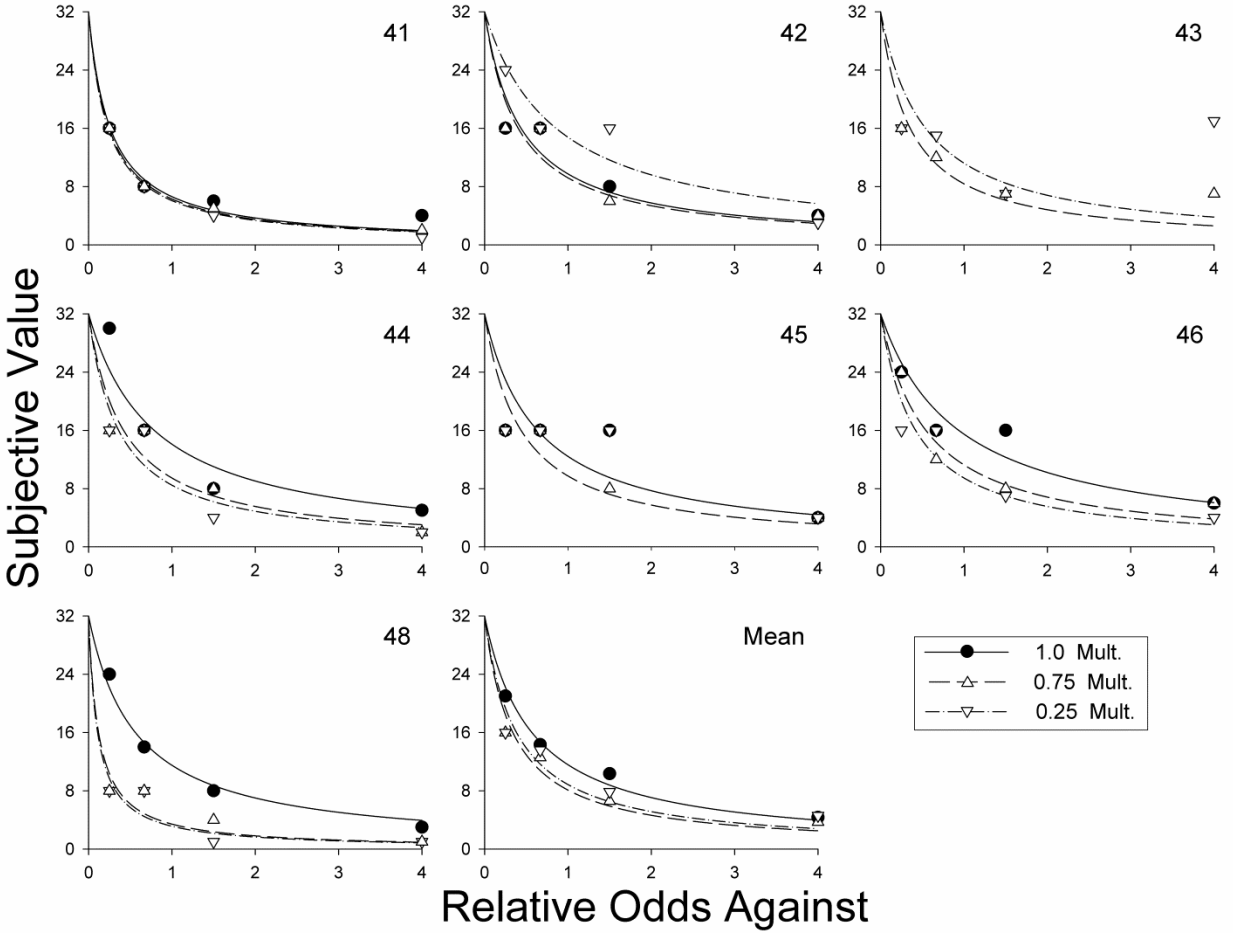

Figure 8. Subjective value of the 32-pellet reinforcers at each multiplier plotted as a function of relative odds against. Symbols represent the estimated indifference points, and curves represent the best-fitting hyperbolic discounting function for each pigeon and for the group means. The 1.0 multiplier is represented by solid curves and filled circles; the 0.75 multiplier is represented by dashed curves and open triangles; and the 0.25 multiplier is represented by dash-dotted curves and open inverted triangles.

amounts x 3 multipliers). Pigeon 47's data were excluded from the analysis because it did not complete the 32-pellet condition. There were no significant effects of multiplier, $F(2, 12) = 0.33$, $p = 0.725$, or amount, $F(1, 6) = 0.03$, $p = 0.871$, and there was no interaction, $F(2, 12) = 1.41$, $p = 0.285$.

Table 3. Proportions of variance accounted for (R^2), discounting rate parameters (b), and root mean square error (RMSE) for the 16- and 32-pellet discounting functions for each pigeon and for the mean in Experiment 2. There are three discounting functions (one for each multiplier) for each of the two amounts.

		R^2			b			RMSE		
		Multiplier			Multiplier			Multiplier		
Pigeon	**Amount**	**0.25**	**0.75**	**1**	**0.25**	**0.75**	**1**	**0.25**	**0.75**	**1**
41	16	.97	.97	.95	1.82	1.80	1.41	0.044	0.039	0.055
	32	.99	.99	.92	4.28	4.09	3.85	0.016	0.013	0.041
42	16	.77	.00	.71	2.39	2.03	2.29	0.088	0.153	0.088
	32	.86	.75	.71	1.17	2.48	2.29	0.087	0.088	0.088
43	16	.91	.99	.00	0.74	4.22	3.80	0.071	0.011	0.127
	32	.00	.50	---	1.86	2.827	---	0.227	0.083	---
44	16	.71	.86	.94	2.62	0.49	1.18	0.161	0.111	0.065
	32	.79	.77	.88	2.78	2.39	1.27	0.094	0.088	0.103
45	16	.88	.58	.88	3.71	1.71	3.71	0.053	0.156	0.053
	32	.16	.71	.16	1.58	2.29	1.58	0.149	0.088	0.149
46	16	.91	.96	.94	1.31	1.67	1.17	0.072	0.044	0.050
	32	.73	.92	.86	2.38	1.84	1.07	0.086	0.060	0.074
47	16	.97	.77	.94	1.82	2.39	1.79	0.044	0.088	0.063
48	16	.00	.06	.51	17.4	11.1	9.351	0.068	0.079	0.049
	32	.66	.48	.98	9.22	8.35	1.78	0.064	0.066	0.036
Mean	16	.98	.94	.97	2.22	2.02	2.21	0.031	0.043	0.030
	32	.76	.88	.97	2.61	2.95	1.76	0.070	0.052	0.032

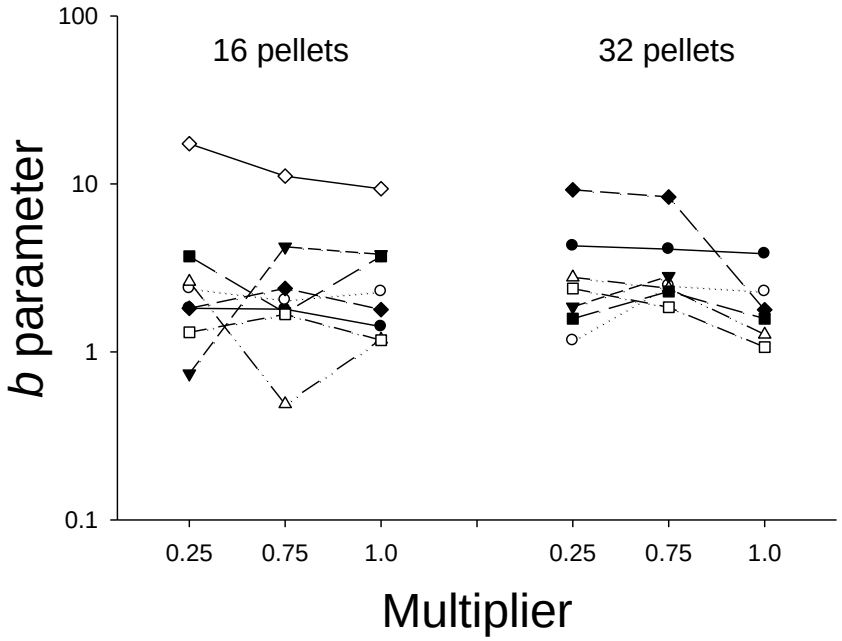

Figure 9. Values of the *b* parameter for each multiplier at each amount. Each pigeon is represented by the same symbol-curve combination for both amounts. Note the logarithmic scale on the *y*-axis.

Analysis of the AuCs showed a similar pattern of results. Figure 10 shows the AuCs for each pigeon and the group means for all conditions. Despite individual variability, it is clear that no systematic effect of either multiplier or amount is present. A two-factor, repeated measures ANOVA (2 amounts x 3 multipliers) showed no significant effects of multiplier, $F(2, 12) = 0.48$, $p = 0.628$, or amount, $F(1, 6) = 0.08$, $p = 0.787$, and there was no interaction, $F(2, 12) = 1.62$, $p = 0.242$.

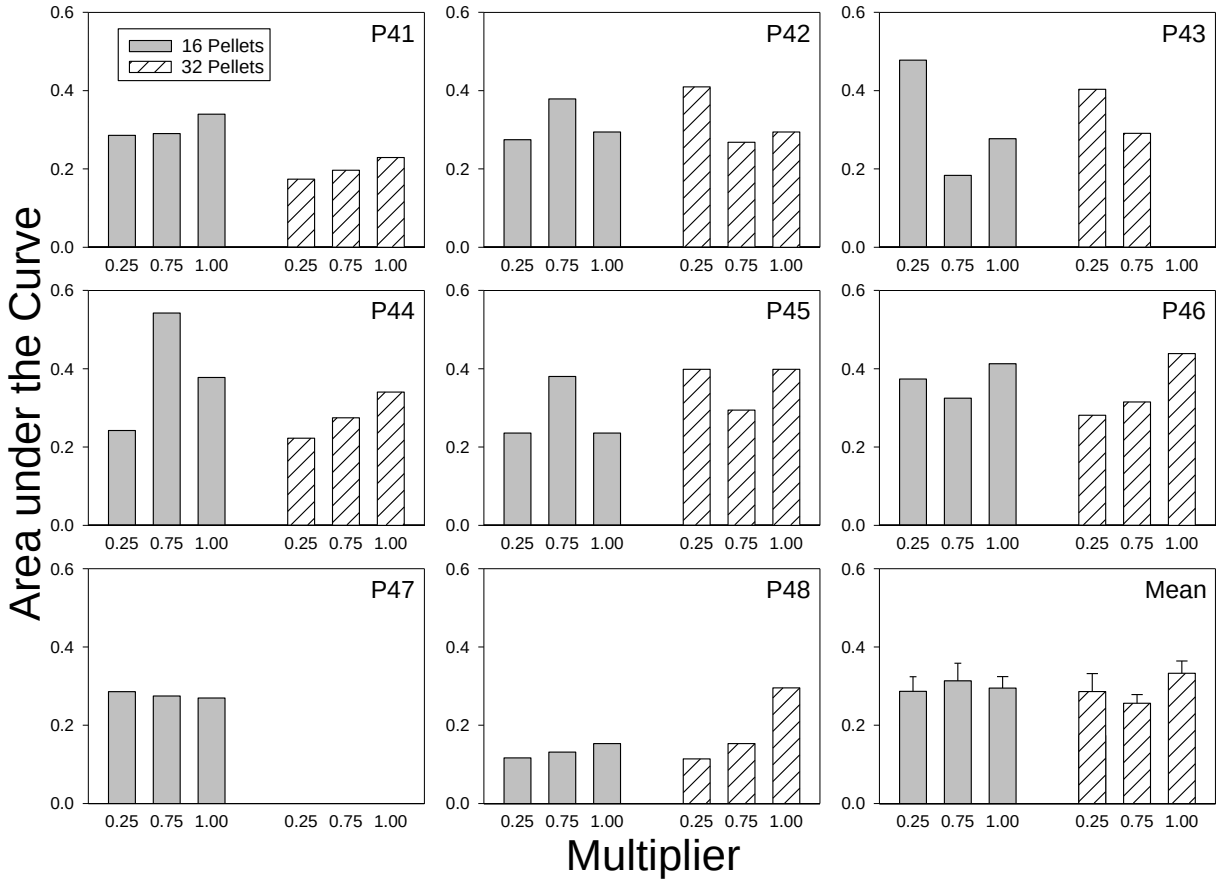

Figure 10. Area under the Curve for the 16- and 32-pellet conditions at each multiplier for each pigeon and for the group means. For the group means (bottom right panel), error bars represent standard error of the mean.

To provide a better way to visualize and compare individual performances under the 16- and 32-pellet conditions, and given that no consistent differences were apparent between the different multipliers, the results of the three multipliers for each amount were averaged for each pigeon. Figure 11 shows the relative subjective value of both amounts plotted as a function of the relative odds against their receipt. It can be seen that there are no systematic differences between the discounting of 16 and 32 food pellets. A simple hyperbola was again used to fit the data. The obtained individual fits were good, with a median R^2 of .90 and a mean of .73. Table

4 presents the estimates of the R^2 values, the discounting rate parameter (*b*), and the RMSE values for each pigeon (except P47) and for the group means at each amount.

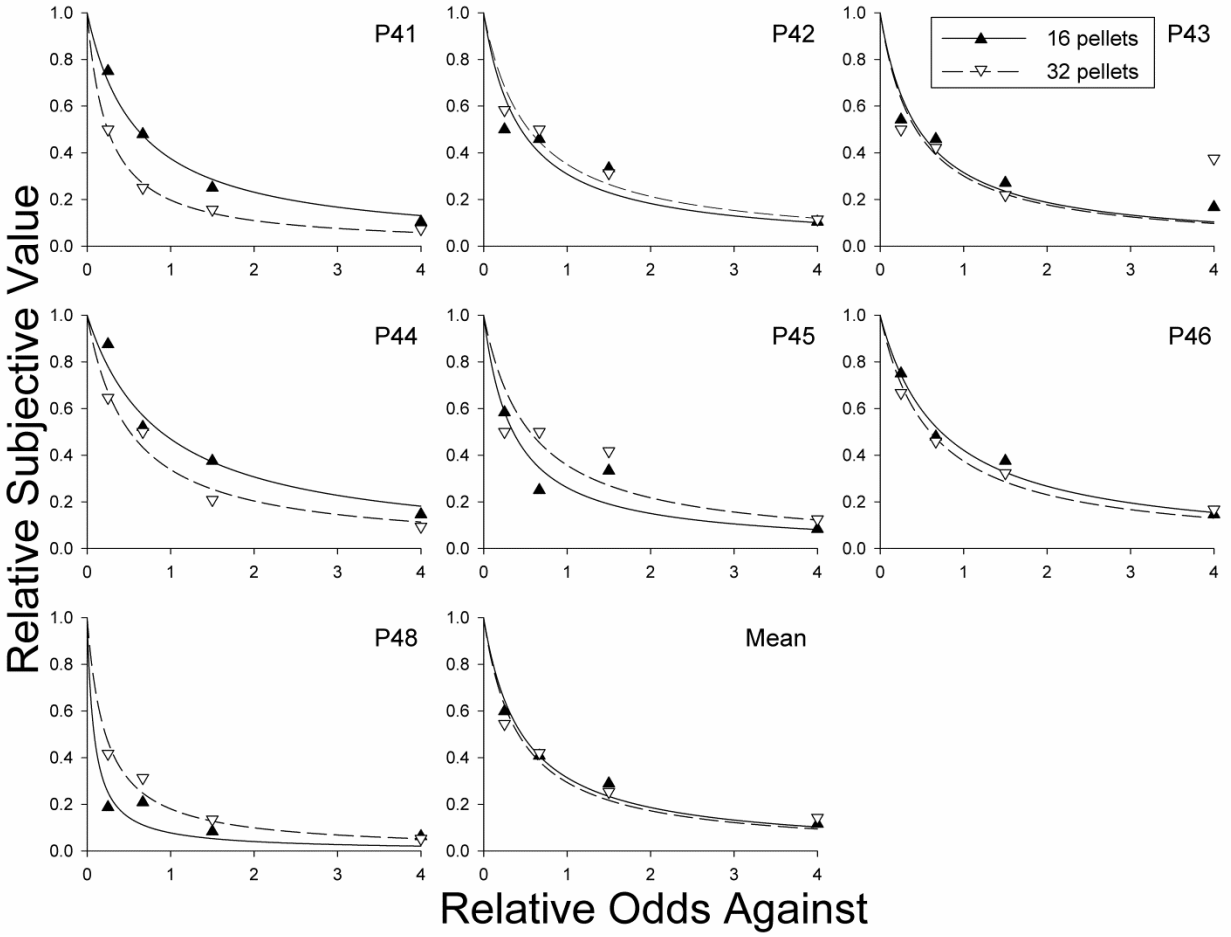

Figure 11. Relative subjective value of the 16- and 32-pellet reinforcers plotted as a function of relative odds against. For each pigeon, the values obtained from the three multipliers conditions were averaged (except P43 at 32 pellets who only ran on two of the multiplier conditions). The 16-pellet amount is represented by solid curves and filled triangles; the 32-pellet amount is represented by dashed curves and open inverted triangles.

These results extend the conclusions drawn in Experiment 1 to situations in which both reinforcers are probabilistic. Specifically, the discounting of probabilistic reinforcers was similar to that of delayed reinforcers, the hyperbolic model provided a good description of the results, and no amount effect was observed. Additionally, no differences were observed between the

levels of discounting under different multipliers, which is to say that no certainty effect was observed. The absence of an amount effect and a certainty effect is inconsistent with what is typically found in humans. Whether these differences reflect procedural differences or a true species difference is a matter that will receive further consideration in the General Discussion.

Table 4. Proportions of variance accounted for (R^2), discounting rate parameters (b), and root mean square error (RMSE) for the 16- and 32-pellet discounting functions for each pigeon and for the mean in Experiment 2. The data were obtained by averaging the data from all conditions on each multiplier.

Pigeon	Amount	R^2	b	RMSE
41	16	.98	1.664	0.031
	32	.99	4.071	0.015
42	16	.64	2.240	0.092
	32	.88	1.850	0.061
43	16	.78	2.170	0.069
	32	.00	2.326	0.155
44	16	.95	1.131	0.057
	32	.96	1.958	0.043
45	16	.77	2.835	0.086
	32	.37	1.802	0.122
46	16	.98	1.374	0.033
	32	.97	1.670	0.033
48	16	.00	11.931	0.063
	32	.92	4.544	0.041
Mean	16	.96	2.183	0.037
	32	.88	2.403	0.053

Experiment 3

Experiment 3 uses the same concurrent-chains and adjusting-amount procedure as that in the previous two experiments to study pigeons' discounting of delayed reinforcers. If the results show orderly discounting functions that are well described by the hyperbolic (i.e., Equation 1 with s set equal to 1.0) function, then one can conclude that the combination of concurrent-

chains and adjusting-amount procedures is a valid technique for studying discounting, and of most significance, for studying probability discounting. Accordingly, the goal of the first phase of Experiment 3 was to determine whether the data obtained with concurrent-chains procedures, like those obtained with adjusting-amount procedures, are well described by a simple hyperbola.

As noted in the Introduction, the absence of an amount effect in animals has not been unequivocal in studies that used concurrent-chains procedures. For example, Grace et al. (2012) observed an amount effect consistent with those reported with humans, and Orduña et al. (2013) reported a reverse amount effect. The second phase of Experiment 3 was designed as a systematic replication of the first that would allow us to evaluate whether an amount effect would be observed when the amount of the delayed reinforcer was changed. The same pigeons were studied in the second phase using the same procedure and delays as in the first phase, but with the amount of the delayed reinforcer reduced by half (from 32 pellets in Phase 1 to 16 pellets in Phase 2). If the degree of discounting increased when the amount of the delayed reinforcer was reduced to 16 pellets, such a finding would be evidence for an amount effect similar to that observed with humans.

Method

Subjects

Ten male White Carneau pigeons (*Columba livia*), all of whom had previous experience with discounting procedures (but not with concurrent-chains procedures), initially were used as subjects. Two did not successfully complete the two pre-experimental control conditions (see below), and thus were not used in the experiment proper. The other eight pigeons completed all experimental conditions. Housing and feeding conditions were identical to those described in Experiment 1.

Apparatus

The two experimental chambers used in this experiment were identical to those used in the previous experiments, with two exceptions. First, a triple-cue light, centered on the panel and equipped with a green, yellow, and red bulb, located 26.5 cm above the grid floor, was added to the chamber. Second, no photobeam device (to detect head entry) was included in the food magazine.

Procedure

The structure of the sessions, as well as the method for assessing the points of indifference, were the same as those described in Experiment 1. The structure of the trials was also the same with a few exceptions. First, the larger reinforcer was received after a delay (1, 3, 6, 10, or 20 seconds in the different conditions) rather than with a given probability. Second, in the terminal link for the smaller, immediate reinforcer, after the red key turned off, the red cue light flashed once (for 0.3 s), after which the small reinforcer amount was delivered; in the terminal link for the larger, delayed reinforcer, after the green key turned off, the green cue light flashed (0.3 s on, 0.3 s off) for the duration of the delay. Third, the ITI (with corresponding blackout) was initiated 5 s after the last food pellet had been delivered.

The experiment consisted of two pre-experimental control conditions followed by two experimental phases, and each experimental phase consisted of five delay conditions.

Control conditions

Prior to the experiment proper, two control conditions were conducted. These conditions determined whether the pigeons were sensitive to the amounts of and delays to reinforcement that were to be used in the experiment proper. In the first control condition, the pigeons chose between 32 pellets to be delivered immediately (from the left red key terminal link) and 32

pellets to be delivered after a 10 s delay (from the right green key terminal link). In the second control condition, the pigeons chose between 16 pellets (left, red key terminal link) and 32 pellets (right, green key terminal link), both of which were delivered immediately.

Each control condition ran for a minimum of 14 sessions, and until stability was achieved. For stability, the last nine sessions were divided into three, 3-session blocks. Behavior was considered stable when (a) the median of each of these blocks did not show a trend (i.e., neither $Md_1 > Md_2 > Md_3$, nor $Md_1 < Md_2 < Md_3$), and (b) the last five sessions showed no visual trend. The pigeon was considered to be sensitive to the difference in delay or amount between the reinforcers if its mean relative rate of responding in the initial link on the key associated with the shorter delay (control condition 1) or the larger amount (control condition 2) was greater than .55 (based on the final five sessions).

Experimental conditions

The experiment proper consisted of two phases, each consisting of five conditions. In the first phase, the delayed reinforcer was 32 food pellets, and in the second phase the delayed reinforcer was 16 food pellets. Each delayed amount was studied at five delays (1, 3, 6, 10, and 20 s), and in both phases, each pigeon experienced the five delays in a different order (see Appendix E for the order in which each pigeon experienced the conditions).

The mean number of sessions was 24.9 (*SD* = 10.8; range = 7-51) for the 16-pellet conditions and 27.9 (*SD* = 15.2; range = 7-62) for the 32-pellet conditions (see Appendix F for the number of sessions each pigeon was studied on each condition in each phase).

Results

Because all the pigeons had extensive experience with different discounting procedures (but not with a concurrent-chains procedure), no training was required. Of the ten pigeons

selected to run in the study, two did not meet the criterion required to pass the two control conditions (i.e., > 55% preference for the sooner reinforcer in control condition 1 and for the larger reinforcer in control condition 2) and did not proceed to the experiment proper. Table 5 shows the mean preference for the sooner (measured by the percentage of key pecks on the left key during the initial link in Control Condition 1) and for the larger reinforcer (measured by the percentage of key pecks on the right key during the initial link in Control Condition 2) from the last five sessions of each of the two control conditions.

Table 5. Mean relative preference (measured by the percentage of pecks) for the sooner reinforcer (Control Condition 1) or larger reinforcer (Control Condition 2) of the last five sessions for each condition.

Pigeon	**Control 1**	**Control 2**
33	73	62
36	79	60.2
38	75	59.4
39	66.2	56.4
82	79.8	60
83	58.8	59.8
84	71.6	58.2
86	60.6	64.8

Figure 12 shows the relative subjective values of the delayed reinforcers (i.e., the amount of the immediate reinforcer at the indifference point as a proportion of the amount of the delayed reinforcer) plotted as a function of delay for both the smaller (16 pellet) and larger (32 pellet) reinforcement phases for each pigeon and the group means (bottom right panel). In all cases, the subjective value of the delayed reinforcers tended to decrease systematically as the delay to their receipt increased. The data were fitted to the simple hyperbola (Equation 1 with *s* set equal to

1.0)[3], and the obtained fits were generally good, with a median R^2 of .72 and a mean of .91. Table 6 presents the estimates of the R^2 values, the discounting rate parameter (*b*), and the RMSE values for each pigeon and for the group means for each amount.

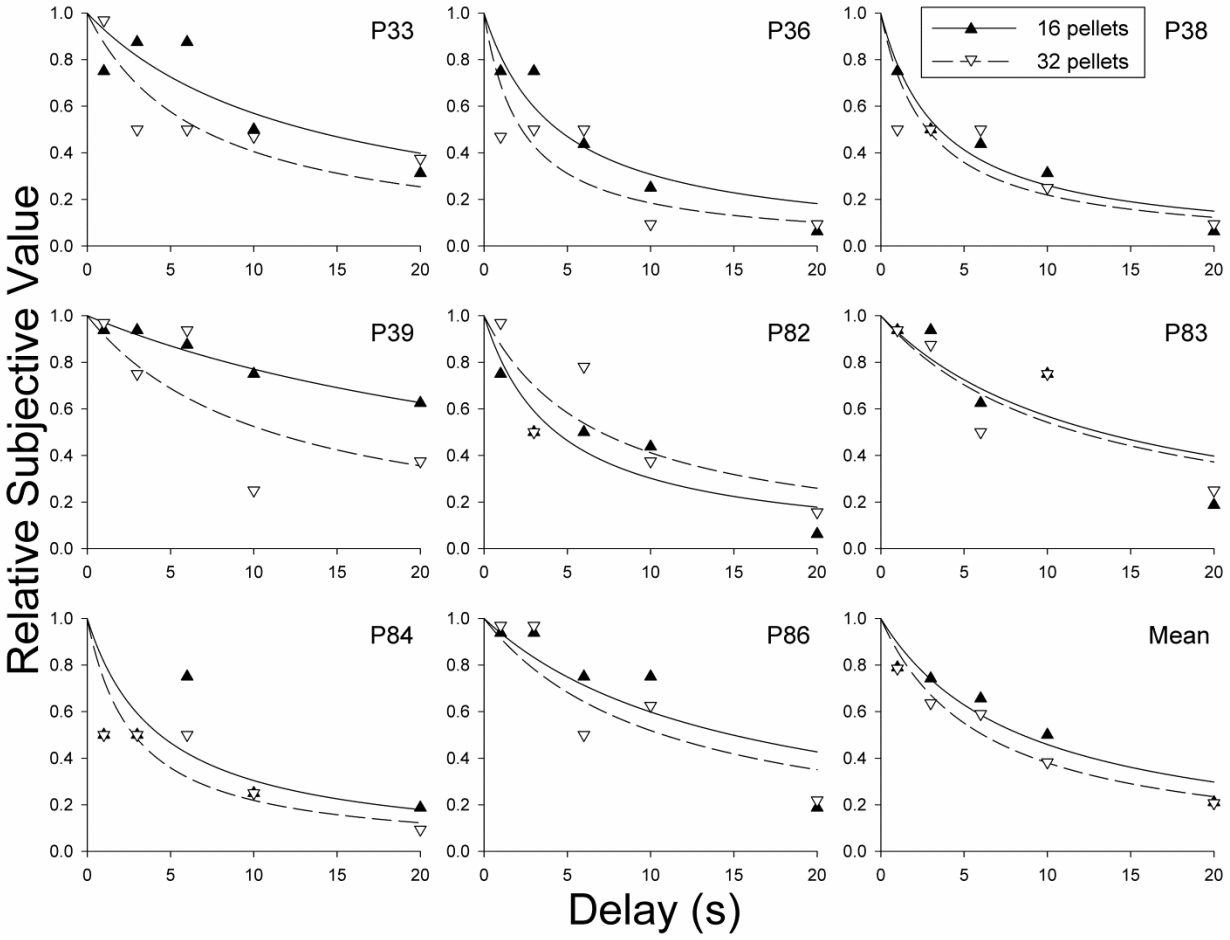

Figure 12. Relative subjective value of the 16- and 32-pellet reinforcers plotted as a function of delay. Symbols represent the estimated indifference points, and curves represent the best-fitting hyperbolic discounting function for each pigeon and for the group means. The 16-pellet amount is represented by solid curves and filled circles; the 32-pellet amount is represented by dashed curves and open circles.

For seven of the eight pigeons (all except P82), the degree of discounting of the larger amount, as measured by the rate parameter, *b*, was greater than for the smaller amount.

[3] The data were also fit using Equation 1 while allowing the *s* parameter to vary. In none of the 16 discounting functions was the *s* parameter significantly different from 1.0.

However, there was no statistically significant difference between the logarithms of the *b* values for the 16- and 32-pellet amounts, $t(14) = 1.02$, $p = .327$.

Table 6. Proportions of variance accounted for (R^2), discounting rate parameters (*b*), and root mean square error (RMSE) for the 16- and 32-pellet discounting functions for each pigeon and for the mean in Experiment 3.

Pigeon	Amount	R^2	*b*	RMSE
33	16	.66	0.076	0.129
	32	.69	0.147	0.116
36	16	.88	0.225	0.095
	32	.39	0.442	0.152
38	16	.93	0.284	0.059
	32	.35	0.357	0.135
39	16	.96	0.030	0.023
	32	.62	0.091	0.181
82	16	.79	0.231	0.100
	32	.71	0.143	0.155
83	16	.75	0.076	0.139
	32	.72	0.084	0.135
84	16	.00	0.229	0.209
	32	.35	0.357	0.135
86	16	.76	0.067	0.136
	32	.79	0.093	0.132
Mean	16	.88	0.118	0.071
	32	.93	0.163	0.054

The degree of discounting of the 16- and 32-pellet amounts also was evaluated by calculating AuC. Figure 13 shows the AuCs for each pigeon at each delayed amount and the group means. Consistent with Figure 12, a small difference between the 16- and the 32-pellet phases is noticeable, with slightly less discounting for the 16-pellet phase. However, there was no statistically significant difference between the 16- and 32-pellet phases, $t(14) = 0.89$, $p = .387$. Therefore, regardless of whether one uses the AuCs or the *b* parameter estimates, no statistically significant difference was obtained between the discounting of 16 and 32 food pellets.

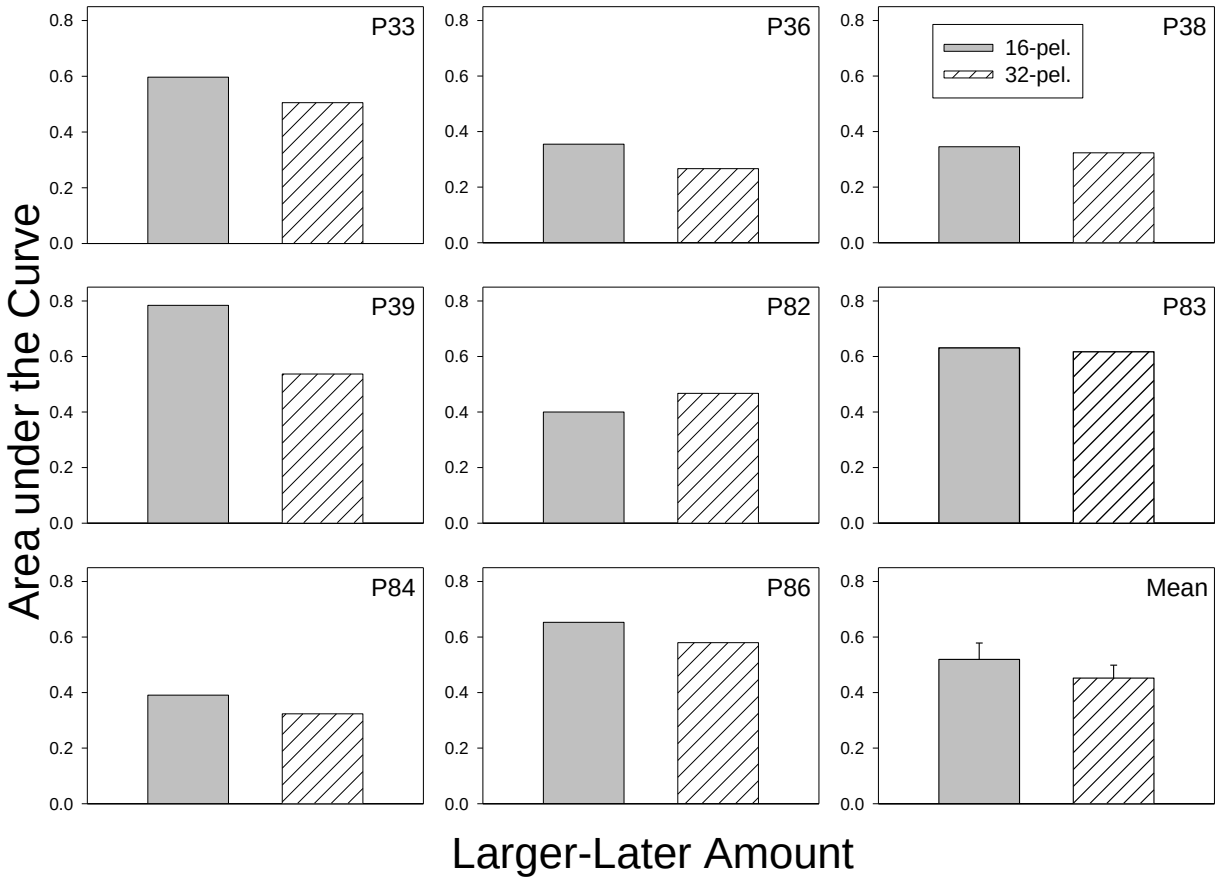

Figure 13. Area under the Curve for the 16- and 32-pellet phases for each pigeon and for the group means. For the group means (bottom right panel), error bars represent standard error of the mean.

Discussion

The results of Experiment 3 are consistent with those reported in other animal delay discounting studies. Specifically, preference for the larger reinforcer decreased as the delay to its receipt increased, and this pattern was well described by the hyperbolic model (Equation 1 with *s* set equal to 1.0). This pattern of findings supports the notion that the current procedure (in which changes in the amount of the smaller-sooner reinforcer were made between sessions based on preferences determined within sessions) is an adequate technique for studying discounting processes in animals.

Furthermore, no significant effect of amount was observed between the discounting of 16 and 32 pellets, although most pigeons showed slightly shallower discounting of the 16-pellet delayed reinforcer, a result opposite that observed with human participants.

It is reasonable to consider that an order effect might be responsible for the small differences observed, given that the 16-pellet phase was conducted after completion of the 32-pellet phase for all pigeons. Previous research suggests that amount of experience can affect delay discounting by increasing self-control (Logue, Rodriguez, Peña-Correal, & Mauro, 1984). However, this explanation seems highly unlikely given the pigeons' extensive experience with delay discounting procedures prior to this study. Logue et al. reported that increases in self-control (i.e., more choices of the larger, more delayed reinforcer) occur over the course of a few sessions. In contrast, all eight pigeons used in Experiment 3 had been run in an experiment using the adjusting-amount procedure over a period of at least one year, in addition to the minimum of 28 sessions required to complete the pre-experimental control conditions in this study. That is to say, the pigeons had extensive experience with discounting and so the effect of that experience would have reached asymptote well prior to the current investigation.

General Discussion

Delay discounting, the process by which a reward loses its value as the delay to its receipt increases, is a fairly well understood phenomenon in both humans and animals. In contrast, although probability discounting, the process by which a reward loses its value as the odds against its receipt increases, has garnered a considerable amount of attention in the human literature (see Green & Myerson, 2004, for a review), there has been a paucity of research devoted to the discounting of probabilistic outcomes in animals.

A few studies have attempted to evaluate probability discounting functions in rats and pigeons. For example, Wilhelm and Mitchell (2008) had rats choose between a smaller, certain reinforcer and a larger, probabilistic reinforcer. Similar to human studies, the rats had a one-shot chance of receiving the probabilistic reinforcer. However, the probabilities experienced within any given session could be quite different from the programmed probabilities, particularly in sessions where the programmed probability was low and/or the rats seldom chose the probabilistic outcome. Green et al. (2010) studied probability discounting by pigeons under VR schedules of reinforcement. Unlike the one-shot scenarios typically presented in human studies, this procedure simulates a repeated-gambles scenario in which the subject always receives the reinforcer, albeit after a different number of attempts (i.e., responses). Furthermore, the probability associated with receiving the reinforcer after a certain number of responses on VR schedules is confounded with the time it takes to complete the schedule requirement. In fact, Green et al. could not conclusively attribute their results to the probabilities associated with the VR schedules because the results also were well accounted for by the time it took the pigeons to complete the VR schedule.

To overcome the shortcomings of previous studies, Experiments 1 and 2 established probability discounting functions with pigeons using an innovative procedure that combined the concurrent-chains and adjusting-amount procedures. Unlike the VR schedules used in the Green et al. (2010) study, the current procedure equated the time from the effective choice response to delivery of the reinforcer. In other words, this procedure ensured that the probability of, rather than the time to, receiving the reinforcer was the variable controlling the pigeons' choices. In addition, use of the adjusting-amount procedure made it possible to vary the amount of the smaller reinforcer according to the relative preference shown during the initial link, thereby

providing an estimate of the indifference point (i.e., the subjective value of the probabilistic reinforcer). Additionally, the concurrent-chains procedure made it possible to simulate a one-shot chance situation similar to that used in research with human subjects. The concurrent-chains procedure also equalized the number of entries into each of the two terminal links, thereby ensuring that the pigeons received equal exposure to both outcomes and experienced the actual probabilities programmed for each outcome in every session.

It was previously noted (see Introduction) that the use of a non-independent VI schedule in the initial link has the distinct advantage of equalizing entries into the two terminal links, thereby ensuring that experienced probabilities equal those programmed, but that the procedure likely also causes the pigeons' preferences to be less extreme than otherwise might be the case. The results obtained in the control conditions of Experiment 3 (Table 5) are consistent with this notion. It may be seen that the degree of preference for the most advantageous outcome was less extreme than might have been expected. It is important to note, however, that the purpose of the experiments was not to assess degrees of preference for different outcomes, but rather to determine points of indifference between reinforcers associated with different probabilities or delays. In order to obtain indifference points even under situations in which the pigeon's preferences might be less extreme than they might otherwise have been, the criterion used for indifference between both outcomes was particularly stringent (i.e., between 45% and 55% of the responses to each choice key). The results of all three experiments, showing sensitivity to the probability and delay contingencies and an overall pattern of discounting consistent with the animal discounting literature, strongly suggest that the adoption of this indifference criterion was sufficient to overcome this limitation.

In Experiment 1, pigeons chose between a smaller, certain amount and a larger, but probabilistic amount. Two food amounts (16 and 32 pellets) were studied at each of five different probabilities (0.9, 0.75, 0.5, 0.25, and 0.1). Results showed that as the odds against receiving the reinforcer increased, the subjective value of the reinforcer decreased. The data were well-fitted by a hyperbolic discounting function (Equation 1 with *s* set equal to 1.0). To the best of my knowledge, this is the first study to obtain probability discounting functions in animals in which the choices are presented as one-shot chances and the experienced probabilities equal the programmed probabilities.

A second goal of Experiment 1 was to determine whether there would be an amount effect. Results showed no systematic differences between the discounting of the 16- and 32-pellet probabilistic reinforcers, regardless of whether the comparison was done using the log *b* parameter of Equation 1 or the AuC. This result stands in contrast to what is typically observed in probability discounting studies with humans, where larger probabilistic amounts are discounted more steeply than smaller probabilistic amounts (e.g., Myerson et al., 2011), but is consistent with the lack of an effect of amount on delay discounting in animals.

Experiment 2 sought to extend the results to situations in which both reinforcers were probabilistic. Accordingly, the probabilities associated with the reinforcers (1.0 for the smaller amount; 0.8, 0.6, 0.4, and 0.2 for the larger amount, either 16 or 32 pellets depending on the condition) were each multiplied by three different factors: 1.0 (in this case, the smaller reinforcer remained certain), 0.75, and 0.25. Results were consistent with those from Experiment 1. In all conditions, the degree of discounting increased as the odds against receiving the larger reinforcer increased, and the data were well fitted by the hyperbolic discounting model. Also consistent with Experiment 1 was the absence of an amount effect:

There were no systematic differences between the discounting of 16 and 32 food pellets, evaluated either using the log *b* parameter or the AuC measure.

When comparing the results from Experiment 1 and 2 to results obtained in probability discounting experiments with humans, two aspects are noteworthy. First, the degree of discounting shown by the pigeons in Experiments 1 and 2, as measured by the AuC, is comparable to what typically is observed in probability discounting studies with humans at relatively small reward amounts – $10 to $100. At larger amounts, however, humans typically show increased risk-aversion with the result that they discount larger probabilistic amounts proportionally more than smaller probabilistic amounts. As a consequence, unlike the pigeons, they show steeper discounting for larger than for smaller probabilistic amounts and thus an amount effect.

Secondly, regarding the *s* parameter in Experiments 1 and 2, pigeons were similar to humans in that *s* was never significantly greater than 1.0. However, whereas with humans the exponent is very often significantly less than 1.0, with pigeons that was seldom the case. This difference also is consistent with what is typically observed in delay discounting studies, as illustrated by Experiment 3 of the present study (for a review, see Green & Myerson, 2004).

Given that the 1.0 multiplier conditions in Experiment 2 were similar to the conditions studied in Experiment 1 (i.e., choices were between a smaller, certain reinforcer and a larger, probabilistic reinforcer), but with different probabilities, and the same pigeons served in both experiments, we fit the simple hyperbola to the data from all nine probabilities studied (5 from Experiment 1 and 4 from Experiment 2)[4]. Figure 14 shows the relative subjective value of each of the two amounts plotted as a function of the odds against their receipt, for each pigeon and the

[4] The data were also fit using Equation 1 while allowing the *s* parameter to vary. In seven (out of the 16) cases the *s* parameter was significantly less than 1.0: P42, P43, and P48 at 16 pellets, and P42, P43, P45, and P46 at 32 pellets. In no case was *s* significantly greater than 1.0.

group means (bottom right panel). The individual fits were generally good, with a median R^2 of .84 and a mean of .74. Table 7 presents the estimates of the R^2 values, the discounting rate parameter (*b*), and the RMSE values for each pigeon and for the group means at each amount. It can be seen that, on average, the data points obtained in Experiment 2 almost seamlessly merge onto the data pattern obtained in Experiment 1. This supports the notion that amount of experience did not affect the pigeons' discounting behavior.

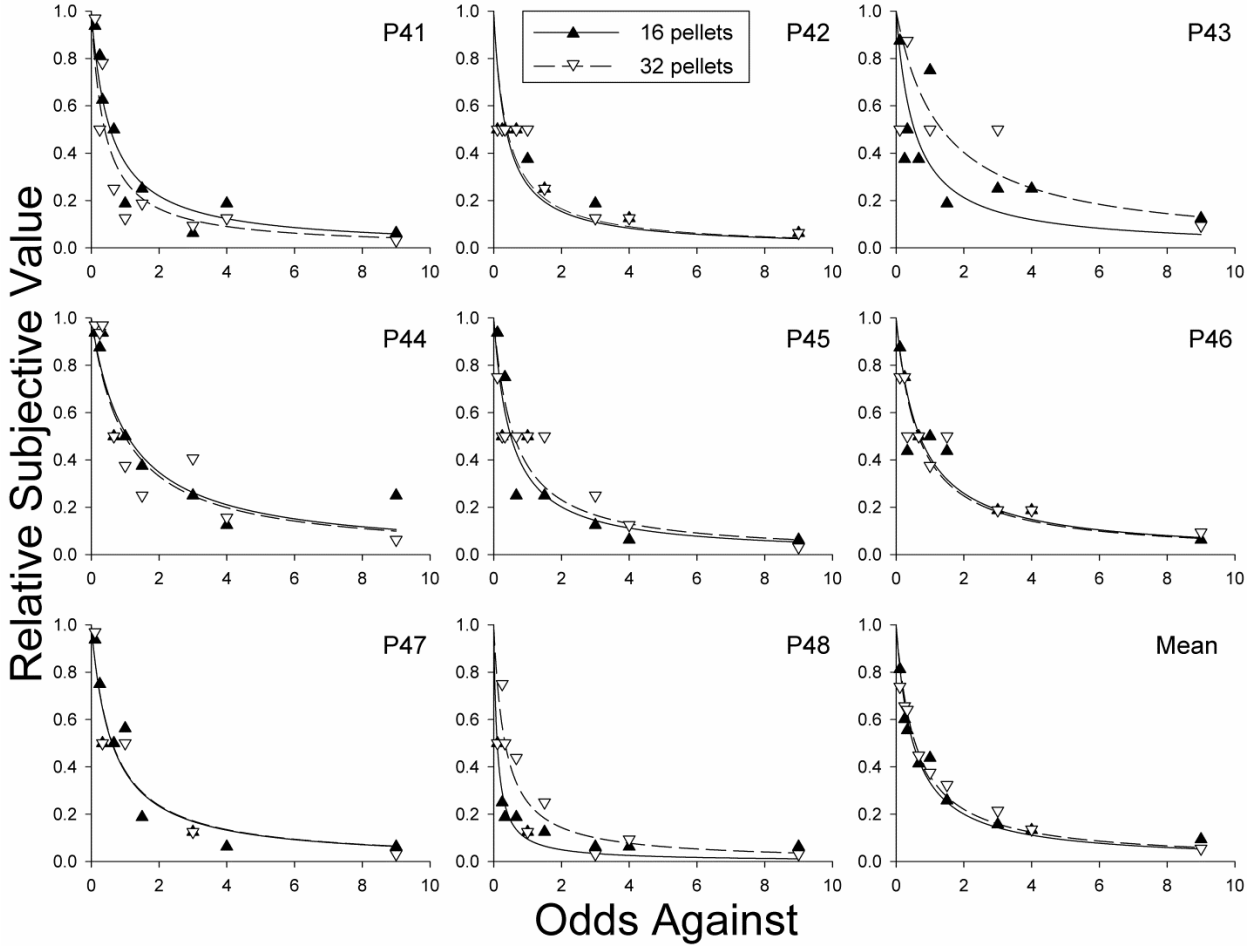

Figure 14. Relative subjective value of the 16- and 32-pellet reinforcers plotted as a function of odds against. Data presented include those obtained in Experiment 1 and those obtained on the 1.0 multiplier conditions of Experiment 2. The 16-pellet amount is represented by solid curves and filled triangles; the 32-pellet amount is represented by dashed curves and open inverted triangles.

Table 7. Proportions of variance accounted for (R^2), discounting rate parameters (*b*), and root mean square error (RMSE) for the 16- and 32-pellet discounting functions for each pigeon and for the mean. The functions include all data from Experiment 1 and from the 1.0 multiplier conditions of Experiment 2.

Pigeon	Amount	R^2	*b*	RMSE
41	16	.92	1.78	0.088
	32	.84	2.53	0.128
42	16	.52	2.75	0.118
	32	.48	2.53	0.133
43	16	.40	1.85	0.187
	32	.25	0.741	0.214
44	16	.90	0.936	0.094
	32	.86	1.01	0.128
45	16	.84	1.98	0.119
	32	.65	1.66	0.126
46	16	.85	1.43	0.095
	32	.82	1.52	0.094
47	16	.90	1.64	0.096
	32	.90	1.61	0.104
48	16	.89	9.57	0.043
	32	.75	2.98	0.120
Mean	16	.96	2.00	0.047
	32	.96	1.77	0.044

Results from Experiment 2 also showed no significant differences among the three multiplier conditions, both at the individual and at the mean level. These results are inconsistent with the 'certainty effect' described in the human literature (Kahneman & Tversky, 1979). This effect refers to the fact that people appear to overweight the value of the certain reward when choosing between a smaller, certain and a larger, probabilistic reward, as compared with choice scenarios in which both rewards are probabilistic but have the same relative probabilities as in the scenario where people choose between certain and probabilistic rewards. If the certainty

effect were to have been observed in Experiment 2, discounting in the 1.0 multiplier conditions would have been steeper than in the 0.75 and 0.25 multiplier conditions.

A phenomenon somewhat related to the certainty effect is the 'Allais Paradox' (Allais, 1953), which describes a preference reversal situation with probabilistic rewards. The Allais Paradox occurs when individuals prefer a smaller, certain (or almost certain) amount to a larger, probabilistic amount of greater expected value, but then reverse their preference and choose the larger amount when the same amounts are each associated with much smaller probabilities, despite the fact that the ratio of their probability is the same. Even though Experiment 2 was not designed to investigate preference reversals (i.e., Experiment 2 produced indifference points rather than degrees of preference at each probability studied), one can infer that, if the pigeons had had a tendency towards reversing their preferences in a manner similar to human participants, then their discounting would have been steepest in the conditions with the 1.0 multiplier and shallowest in the conditions with the 0.25 multiplier. In other words, if the pigeons had overweighted the value of the certain reinforcers, then as the multiplier decreased from 1.0 to 0.75 to 0.25, the pigeons would have shown shallower and shallower discounting whereas in fact, the steepness of their discounting did not change systematically.

These results, however, actually may not be that different from what occurs with humans. For example, Morris (2010) studied humans' choices when both rewards were probabilistic using an experimental design that involved five multipliers: 1.0 (i.e., the smaller reward was certain), 0.5, 0.2, 0.1, and 0.05. Results showed no differences in discounting between the 1.0, 0.5, and 0.2 multiplier conditions. Only with the much smaller multipliers (0.1 and 0.05) did the participants show preference reversals, preferring the larger, less likely reward more often. These results suggest an explanation for the results obtained in Experiment 2 because, as may be

recalled, the lowest multiplier used in that experiment was 0.25. Thus, it is possible that the pigeons would have shown differences in degree of discounting at lower multipliers. Under the procedure used here, however, multipliers as low as 0.05 or 0.1 would require that sessions be far too long. Moreover, the number of reinforcers obtained with such low multipliers might be so few that responding would be difficult to maintain.

Experiments 1 and 2 successfully established reliable probability discounting functions using a procedure that simulated one-shot chance situations and ensured that the experienced probabilities matched the programmed probabilities. The individual data were well fitted by the hyperbolic model, with fits comparable to those obtained in previous animal studies of delay discounting. However, given that the procedure is new and complex, a third experiment was conducted in which the larger reinforcers were delayed rather than probabilistic, so that the results could be compared with those obtained in previous studies that used more typical procedures.

Experiment 3 used eight pigeons without experience with concurrent-chains procedures. The pigeons were presented with choices between a smaller, immediate reinforcer and a larger (16 or 32 pellets) reinforcer delayed by 1, 3, 6, 10, or 20 seconds, depending on the condition. Results showed that as the delay to the larger reinforcer increased, its present, subjective value decreased, and the data were well-fitted by a hyperbolic discounting function. This finding supports the view that the procedure used in these experiments is a valid alternative for the study of discounting mechanisms and could allow for direct comparisons between the effects of different variables on the discounting of delayed and probabilistic reinforcers in animals.

Interestingly, the discounting functions for the pigeons in Experiment 3 were shallower (as indicated by lower discounting rate parameters) than in other pigeon studies that used an

adjusting-amount procedure (Green et al., 2004; Oliveira et al., 2013). Across pigeons and amounts, the mean *b* value was 0.183 in Experiment 3, 0.523 in Green et al. (2004), and 0.624 in Oliveira et al. (2013). This notable difference might be related to the fact that, in previous studies, on each trial the pigeons chose between the two outcomes via a single peck, whereas in Experiment 3 the preference was assessed via the relative rate of response on a VI 30-s schedule. In other words, the pigeons in the current study were responding for a longer period of time and further in advance of when the reinforcer was to be delivered than in previous studies. Previous research suggests that the addition of a common delay to both alternatives produces shallower discounting in pigeons (Calvert, Green, & Myerson, 2011), and this could explain the relatively shallow discounting in Experiment 3.

No statistically significant difference was observed between the delay discounting of 16 and 32 food pellets in Experiment 3, evaluated either by the log *b* parameter or by AuC, although most pigeons showed marginally steeper discounting of the 32-pellet reinforcer (a result opposite that observed with human subjects). The lack of an amount effect in Experiment 3 is consistent with the results of a relatively large number of studies that have investigated the effect of amount on discounting in animals. These studies have used several different procedures and both pigeons and rats. With the exceptions of Grace et al. (2012) which reported an amount effect, and Orduña et al. (2013) and Ong and White (2004, Experiment 1) which reported an opposite amount effect, none of these studies has obtained a statistically significant effect of amount (see Table 8), a finding that stands in stark contrast to what is typically observed with humans.

Table 8. Summary of the pigeon and rat studies investigating the amount effect.

Author	Species	Procedure	Amounts	Result
Richards et al. (1997)	Rat	Adjusting-Amount	100, 150, 200 µL	No amount effect
Grace (1999)	Pigeon	Concurrent-Chains	Food duration varies; 2.5:1 ratio	No amount effect
Green et al. (2004)	Pigeon, Rat	Adjusting-Amount	5, 12, 20, 32 pellets for pigeons; 5, 12, 20 pellets for rats	No amount effect
Ong and White (2004) Expt. 1	Pigeon	Concurrent-Chains	1, 4.5 sec of access	Reverse amount effect
Ong and White (2004) Expt. 2	Pigeon	Concurrent-Chains	1, 4.5 sec of access	No amount effect
Calvert et al. (2010)	Rat	Adjusting-Amount	10, 30 pellets; 100, 500 µL	No amount effect
Grace et al. (2012)	Pigeon	Concurrent-Chains	1, 4.5 sec of access	Amount effect
Orduña et al. (2013)	Rat	Concurrent-Chains	1, 4 pellets	Reverse amount effect
Present study	Pigeon	Adjusting-Amount/ Concurrent-Chains combination	16, 32 pellets	No amount effect

How might one account for the difference between humans and other animals regarding an effect of amount? Orduña et al. (2013) pointed to the fact that the ratios between the different amounts and the types of reward typically used in human and animal studies vary greatly. Indeed, the ratios between the amounts of the delayed reinforcers used in different amount conditions of animal studies range from 2:1, as in the present experiments, to 6.4:1 (Green et al., 2004), whereas with humans, these ratios are typically much higher, with reward amounts differing by up to several orders of magnitude (e.g., Green et al., 2013). Moreover, the outcomes in animal studies are primary reinforcers, whereas in human studies the rewards are most often hypothetical (whether monetary, consumable, or a different commodity such as vacation time). Nevertheless, Johnson and Bickel (2002) observed consistent amount effects in humans with

both real and hypothetical monetary rewards and with ratios between the monetary amounts as low as 2.5:1. Furthermore, Jimura et al. (2009) observed an amount effect in humans using real juice rewards – a primary reinforcer – and a ratio of only 2:1.

As pointed out by Grace et al. (2012) and Orduña et al. (2013), another possible reason for the inter-species difference with regard to an amount effect relates to the discriminability or contrast between the amounts of delayed reward. In human studies, participants usually experience all amounts over the course of a single experimental session. In the present work and other animal studies that used the adjusting-amount procedure, subjects are often exposed to the same delayed reinforcer amount for several weeks at a time (cf. Richards et al., 1997, and Wilhelm & Mitchell, 2008, who varied the standard amount on a daily basis). Consistent with this suggestion, the amount effects observed in animal studies that varied amounts within sessions (Grace et al., 2012; Ong & White, 2004; Orduña et al., 2013) could have been due in part to an enhanced discrimination between the two standard amounts. Of course, this possibility still would not explain the fact that the amount effects reported by Ong and White as well as Orduña et al. were the opposite of those observed with humans.

It is important to note that the finding that animals' discounting is not affected by the amount of delayed reinforcement is consistent with the view, exemplified by the matching law (Herrnstein, 1970), that choices are controlled by the relative, rather than the absolute, value of reinforcers. Other evidence consistent with this view is the finding that when rats choose between immediate and delayed amounts of the same reinforcer, the degree to which they discount the delayed reinforcers is the same regardless of the quality of the reinforcers involved (Calvert et al., 2010). That is, the rats in the Calvert et al. study strongly preferred saccharin-flavored water to quinine-flavored water, but their choices between immediate and delayed

liquids were the same, regardless of whether both were saccharin flavored or both were quinine flavored. In addition, Oliveira et al. (2013) reported that the degree to which pigeons discounted delayed food reinforcers was not affected by their level of deprivation. Finally, in Experiment 2 of the present effort, pigeons showed no differences between the degree of discounting under several different probabilities, but with the relative likelihood of the smaller and larger reinforcer amounts kept constant. If amount, quality, deprivation, and relative probability result in proportionally equivalent changes in the value of alternative reinforcers, leaving preference between the alternatives unchanged, then it would be expected that manipulations of these independent variables would not affect discounting rates. Thus, the question is not why do animals not show an amount effect, but why humans do.

Considerably more research will be needed to more fully understand how animals choose between outcomes associated with varying degrees of risk. The procedure used in the present effort offers the opportunity to study the effect of different variables (e.g., drugs, brain lesions) on the discounting of probabilistic reinforcers in different animal species (e.g., rats and monkeys). Importantly, this new procedure will allow researchers to directly compare delay and probability discounting processes by using near-identical tasks, and to investigate how animals discount reinforcers that are both delayed and probabilistic (i.e., a chance of obtaining a delayed reinforcer), a situation that reflects many everyday choices.

Other important aspects to explore in the study of how animals choose between probabilistic outcomes are the certainty effect and preference reversals. It is possible that, similarly to what occurs with humans, these effects can only be observed when extremely low probabilities are introduced. If that is the case, then the procedure used must ensure that the animals keep responding even with very thin reinforcement schedules.

At this point, comparative research on the amount effect must continue addressing the procedural differences between human and animal studies. For example, it would be important to conduct more animal studies in which the discrimination of the different variables is enhanced (e.g., by having the animals experience the different amounts and delays or probabilities within the same session, as is typically the case in a human experiment; see Grace et al., 2012, and Orduña et al., 2013).

Kinloch and White (2013) used a concurrent-chains procedure with humans that was similar to the one used by Grace et al. (2012) who studied delay discounting by pigeons and obtained similar results, namely steeper discounting for the smaller reward amount ($20) than for the larger reward amount ($2,000). It would be important to also use a concurrent-chains procedure similar to the one developed in this study to evaluate discounting by humans. Of particular interest would be to compare the delay and probability discounting functions obtained using a concurrent-chains procedure with those typically observed using different procedures. Also of interest would be to determine whether humans show an amount effect, especially if the amounts tested have small ratios between them. The presence of an amount effect in those circumstances would strengthen the suggestion that it constitutes a true species difference, and is not simply due to methodological discrepancies.

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Appendix A

Order in which conditions were studied for each pigeon in Experiment 1.

		Probability				
Pigeon	**Amount**	**0.1**	**0.25**	**0.5**	**0.75**	**0.9**
41	16	5	3	1	2	4
	32	7	9	6	10	8
42	16	4	2	1	3	5
	32	8	10	6	7	9
43	16	9	7	6	8	10
	32	2	4	1	5	3
44	16	10	8	6	9	7
	32	4	2	1	3	5
45	16	3	4	1	2	5
	32	9	7	6	10	8
46	16	3	2	1	4	5
	32	7	9	6	8	10
47	16	10	8	6	7	9
	32	2	4	1	3	5
48	16	8	10	6	9	7
	32	5	3	1	2	4

Appendix B

Number of sessions to obtain a subjective value estimate of the 16- and 32-pellet probabilistic amounts for each condition in Experiment 1.

		Probability				
Pigeon	**Amount**	**0.1**	**0.25**	**0.5**	**0.75**	**0.9**
41	16	21	23	81	56	22
	32	29	58	23	34	28
42	16	22	29	52	7	14
	32	35	34	19	21	8
43	16	25	43	35	8	28
	32	39	15	7	28	24
44	16	32	37	23	26	21
	32	43	48	52	66	28
45	16	21	27	34	28	41
	32	34	23	13	11	16
46	16	23	47	38	24	31
	32	42	49	43	11	17
47	16	21	45	42	19	43
	32	39	52	32	19	34
48	16	21	23	20	23	18
	32	28	41	57	17	10

Appendix C

Order in which conditions were studied for each pigeon in Experiment 2.

			Probability			
Pigeon	**Amount**	**Multiplier**	**0.2**	**0.4**	**0.6**	**0.8**
41	16	0.25	1	3	2	4
		0.75	6	5	8	7
		1.0	10	12	9	11
	32	0.25	19	13	20	16
		0.75	17	15	18	14
		1.0	24	22	23	21
42	16	0.25	5	7	8	6
		0.75	2	4	3	1
		1.0	11	9	10	12
	32	0.25	18	16	19	15
		0.75	20	14	17	13
		1.0	22	24	21	23
43	16	0.25	11	9	12	10
		0.75	4	2	1	3
		1.0	8	6	7	5
	32	0.25	19	15	20	16
		0.75	17	13	18	14
		1.0	--	--	--	--
44	16	0.25	10	9	12	11
		0.75	3	4	1	2
		1.0	5	7	6	8
	32	0.25	17	15	20	14
		0.75	19	13	18	16
		1.0	22	24	23	21
45	16	0.25	1	3	2	4
		0.75	10	12	9	11
		1.0	6	5	8	7
	32	0.25	19	13	18	14
		0.75	17	15	20	16
		1.0	22	24	23	21

46	16	0.25	5	7	8	6
		0.75	11	9	10	12
		1.0	2	4	3	1
	32	0.25	18	13	19	16
		0.75	20	15	17	14
		1.0	22	24	21	23
47	16	0.25	11	9	12	10
		0.75	8	6	7	5
		1.0	4	2	1	3
48	16	0.25	10	9	12	11
		0.75	5	7	6	8
		1.0	3	4	1	2
	32	0.25	19	14	17	13
		0.75	18	16	20	15
		1.0	21	23	24	22

Appendix D

Number of sessions to obtain a subjective value estimate of the 16- and 32-pellet probabilistic amounts for each condition in Experiment 2.

			Probability			
Pigeon	**Amount**	**Multiplier**	**0.2**	**0.4**	**0.6**	**0.8**
41	16	0.25	36	46	23	21
		0.75	23	26	26	69
		1.0	49	21	8	72
	32	0.25	37	35	47	20
		0.75	28	52	14	7
		1.0	27	57	22	14
42	16	0.25	26	34	23	14
		0.75	30	29	51	7
		1.0	24	50	9	10
	32	0.25	54	7	15	23
		0.75	37	39	23	10
		1.0	34	23	8	8
43	16	0.25	57	14	33	24
		0.75	30	24	22	8
		1.0	33	47	42	32
	32	0.25	31	44	41	23
		0.75	60	53	63	35
		1.0	--	--	--	--
44	16	0.25	34	32	41	64
		0.75	45	18	21	21
		1.0	36	82	13	28
	32	0.25	39	24	10	13
		0.75	28	17	7	9
		1.0	46	29	7	40
45	16	0.25	27	21	20	15
		0.75	21	23	23	22
		1.0	24	17	19	8
	32	0.25	44	13	9	9

		0.75	45	28	13	11
		1.0	23	10	9	10
46	16	0.25	29	32	25	50
		0.75	24	18	32	17
		1.0	38	35	13	38
	32	0.25	29	88	11	23
		0.75	37	21	35	27
		1.0	43	13	7	18
47	16	0.25	25	44	39	21
		0.75	23	36	19	20
		1.0	21	37	30	23
48	16	0.25	24	24	41	33
		0.75	27	23	21	24
		1.0	21	22	39	21
	32	0.25	33	37	54	21
		0.75	31	38	48	18
		1.0	49	24	82	24

Appendix E

Order in which conditions were studied for each pigeon in Experiment 3.

	Delay (sec)					
Pigeon	1	3	6	10	20	**Amount**
33	9	7	10	8	6	16
	1	3	5	2	4	32
36	7	9	10	8	6	16
	3	1	5	2	4	32
38	6	10	8	7	9	16
	4	2	3	1	5	32
39	10	6	8	9	7	16
	2	4	1	3	5	32
82	9	7	10	8	6	16
	1	3	2	5	4	32
83	7	9	10	8	6	16
	3	1	5	2	4	32
84	10	6	8	9	7	16
	2	4	1	3	5	32
86	6	10	8	7	9	16
	4	2	3	1	5	32

Appendix F

Number of sessions to obtain a subjective value estimate of the 16- and 32-pellet delayed amounts for each condition in Experiment 3.

	Delay (sec)					
Pigeon	1	3	6	10	20	**Amount**
33	25	40	33	7	42	16
	44	11	19	62	33	32
36	22	38	38	24	21	16
	31	16	7	36	55	32
38	23	25	37	35	21	16
	11	7	7	25	38	32
39	21	29	24	16	51	16
	47	14	43	18	34	32
82	14	9	7	24	22	16
	42	13	32	35	44	32
83	32	33	49	17	26	16
	31	21	9	23	33	32
84	8	9	15	18	26	16
	9	10	9	19	35	32
86	21	21	26	19	28	16
	39	47	17	47	44	32